TOOLS OF TO-MORROW

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I

GIFTS WE HAVE NOT LEARNED TO USE

A FEW years ago a Western explorer spent the night at a lamasery in Central Asia. He was treated kindly by the monks and in payment left them a thrilling and fascinating gift—the catalogue of a big store. Before he said good-bye he explained the supernatural powers of the book. The monks could hardly believe their ears, but he assured them that all the incredible objects illustrated between its gaudy covers might be obtained merely by sending money.

The monks had plenty of money in the treasury, but for some time they did not trust their good fortune. At last they found a Chinaman who knew how to work the spell. He filled out the magic pages in the back of the book and sent them by courier, yak, and camel to the store.

After six months or so the gifts began to arrive, and soon the lamasery was cluttered with mysterious things. An electric refrigerator stood in the audience hall, stuffed with parchment prayers. Strips of bright linoleum hung on the walls. Washing-machines, motor lawn-mowers, disk-harrows, and typewriters clogged the courtyard, objects of veneration if not of use.

But the daily life of the lamasery changed very little if at all. There was no petrol for the lawn-mower. There were no lawns for it to mow. There was no current for the refrigerator. No one thought of putting

the linoleum on the floor. The head lama took to wearing a silk dressing-gown on state occasions, and his monks found that an egg-whisk, properly inscribed, made a very efficient prayer-wheel. But that was all. The magic book was called upon from time to time for more gifts, but the lamasery never came to resemble a small Western town.

The civilized world to-day is much like this perhaps mythical lamasery. We too have a magic book, applied science, which will give us almost every material thing we ask for. The editions appear at yearly intervals, or less, and each one contains extraordinary new items which we are not able to use because we cannot fit them into the structure of our civilization. The new materials, methods, machines, and conveniences have to wait until we have carved a niche to contain them.

We may call this phenomenon " technical lag ", if we want a handy term, but not all of the causes behind it are technical. Like a prudent army, civilization has to protect its flanks ; it cannot send small parties too far ahead of the main body. Aeroplane instruments, for instance, if manufactured in lots of a hundred thousand, would probably sell at one-tenth the price they bring to-day and would be better instruments. But this cannot be done before a similar advance has filled the skies with aeroplanes, which in turn require pilots to fly them and airports for them to land upon. " Sabotage " by motor-car and railway companies would have to be overcome. Financial battles would have to be fought in the City of London, Wall Street, and the Paris Bourse. Governments would take a hand, for such a development in one country would alarm its neighbours and possibly cause a war.

So it is in every field of applied science. Technology can advance only a certain distance ahead of the industries which support it. The industries have to wait for a market for their products. And the market in turn

is affected by all sorts of non-technical factors : economic conditions, politics, custom, and fashion.

At present the most nearly universal limiting factor is economic. Many excellent devices have been developed which would be used widely if our creaking economic system could provide the public with sufficient purchasing power. Automatic heating and cooling of dwelling houses is an example. Every family would enjoy such an improvement, and there is no serious technical obstacle to its widespread use. The only barrier is the high cost, which would be reduced very greatly if the public had enough money to support a large-volume industry.

Sometimes the trouble is political in a narrower sense. There is hardly a single article in the world to-day which could not be produced better and cheaper if the network of tariffs, quotas, and subsidies were removed. Economic nationalism is a wasting disease which stunts every twig of technical civilization.

Often improvements are delayed by wholly non-rational factors. We could have much better motor-cars, for instance, if the public were to demand efficiency and comfort instead of conventional style and social prestige. We could live in very inexpensive and agreeable factory-built houses if architectural tradition did not conflict with the new materials and methods.

In this book I am not going to waste time railing against such obstacles. They are firmly founded upon the fact that the collective mind of humanity has not developed as fast as applied science. They can be reduced only gradually. No reform will be able to remove them all at one blow.

What I shall do is describe the most important new items in our big store catalogue. I shall not compile a mere list of interesting gadgets, the end-products of science and invention, but shall concentrate largely on fields of effort which promise to provide us with many

such things. I shall resist the temptation to generalize too broadly, but I do not want to compete with the promotion department of General Electric.

At the outset I must make it plain that I do not consider technology the only force in the world. Civilization is built of human minds, not of machines and technical methods. At present we are trying to solve what we believe to be our material problems by the use of applied science, but there is no telling how long we shall continue on this same road. Our particular civilization may stop dead in its tracks, change its direction, or even be wholly destroyed by non-technical forces.

First among the threats to technological progress is the possibility that the human race may deteriorate physically when the energy-developing function of our muscles has been usurped by power-driven machines. This has happened to some extent already. The average Londoner or New Yorker is weaker than his agricultural compatriot, probably weaker than his grandfather. This is nothing to be alarmed about; physical strength is not as important as it used to be. A much worse condition is the extraordinary drop in the birth-rate of the industrial nations. If this trend continues, it may cut off the human raw material of civilization at its source, the cradle. Perhaps nature realizes that we are training machines to perform many of our duties, and is making adjustments. We hope not.

Then there is the so-called "problem of technological unemployment"—how to organize society so that the lower ranks of the population will not suffer too much when their functions are further usurped by machines. This is no minor or temporary problem. It is fundamental and permanent. It will be with us as long as our civilization continues to develop in its present direction, and if it is not solved in some way, we shall run into a great deal of trouble, perhaps into a period of

confusion resulting in general collapse and the necessity of starting all over again.

Each proposed solution for this problem has its own peculiar dangers. If we try to prevent such unemployment by limiting the application of new labour-saving methods, we shall freeze civilization in its present mould. " Subsistence farms " and regulations against new automatic machines are steps in this direction. So are all other attempts to make the human unit less productive. The Chinese seem to have accomplished a great deal in this line. There is plenty of work for all in China, but nothing much else.

An equally dangerous solution is economic dictatorship, which exists in practice under various names and is proposed under several more. The trouble with all dictatorships alike is their high " freezing-point ". They congeal easily into stagnation. The ruling groups, once they have become satisfied with the *status quo*, are very likely to throttle new developments which threaten their position. It is interesting to note in this connection that none of the dictator-ruled countries are making any scientific or technical discoveries worth mentioning.

Another peril is a general war which will divert the energies of the world away from constructive activities. I do not think that another war will " destroy civilization " in a material sense. It is more likely to hasten development along certain lines by cutting various Gordian knots of economics and finance. The last war stimulated hugely the development of aircraft, mass-production manufacturing, industrial chemistry, and mechanized agriculture. The next war will probably have the same effect.

What will happen after the peace treaty is signed is a much more serious matter. Soldiers gain complete control during a war and usually manage to retain a large part of their power after hostilities have ceased. Their habits of hatred and violence make themselves felt for

many years. This is what happened after the last war. Europe in most ways is less civilized and progressive to-day than it was in 1914. Violence is the fashion in many government circles. Reason and persuasion are not. Misleading propaganda has taken the place of the free exchange of ideas so necessary to the growth of civilization. Economic barriers erected by suspicious nationalism have reduced the net efficiency of industry in spite of the technical improvements available. These are the worst effects of war upon civilization, worse even than the damage caused by the guns and gas.

So much for the possible reasons why our civilization may not continue to progress along the technical lines it has followed up to the present. Some of these effects will undoubtedly be felt in some degree. Economic nationalism and the armament race are already a partial war. The drop of the birth-rate is already a partial biological deterioration. "Technological unemployment" will always be with us. We know of no cure which may not prove worse than the disease.

But in this book I am going to ignore these spectres and assume that they will not raise insuperable barriers to technical progress. The recent accomplishments of applied science can make our lives easier, less laborious, and more secure. I shall assume that they will get their chance.

If no novel difficulty makes itself felt, we may expect to see a great deal of development in the next few years. The depression flashed a red light across the road of technical application, but the scientists and inventors did not cease work. Their discoveries were laid aside, packed in moth-balls for better times. Now that the light shows signs of turning green, they are being taken out again. This book will discuss the fields in which the most striking progress is likely to be made. The general plan will be extremely simple. I shall start with power, the use of which makes modern civilization

different from all its predecessors. Then I shall take up metals and alloys. Much of our progress is based upon discoveries in this field. Next will come machines, first those general ones used to produce other things; later the machines of more direct utility, such as vehicles and communication devices. And finally I shall point out a few of the changes which we shall have to make before we can enjoy the ease and luxury which applied science offers us.

II

FOOD FOR MECHANICAL SLAVES

THE RÔLE OF POWER

THE world to-day is attempting a novel experiment in how to live. We call it "modern civilization". The Romans called their civilization "modern". So did the Greeks. So did the Mayas and the Incas, no doubt. But they did not mean what we mean by the word "modern". Their civilizations were all based on the same old idea. Our civilization has a new idea. It is another *kind* of civilization, utterly different, not merely a new peak in the long fluctuating curve of human affairs.

The ancient civilizations, all of them, were founded on the idea of forming co-operative social groups and dividing the necessary work among specialized individuals within them. This was true of small primitive tribes as well as of vast aggregations like China or the Roman Empire. The difference between them was only one of degree.

The theoretical starting-point of this process was the single, isolated man supplying all his own wants without help. We have no record of such "hermit economies". Probably there never were any. Our race may have been gregarious long before it was human. But the wholly rugged individual is a convenient conception.

Such a man might supply his own wants after a fashion, but experience soon proved that he could do it better with assistance. Small groups formed, all the members doing much the same things, but acting in unison. The next step was for certain individuals to

specialize on making weapons or tools, on fishing, hunting, or agriculture. It was found that the specialist was more effective than the jack-of-all-trades.

This type of civilization persists to-day in various places—among certain South Sea Islanders, certain Negroes, certain Indians. If we want a convenient term we may call it " horizontal specialization ". All members of the group remain more or less on a level. All do manual work. There is no governing class to direct but not perform.

The next step we may call " vertical specialization ". It was found that a Boss directing several subordinates was more effective than a group of equals each of whom did his own thinking. The advantage was that in such a group the dullest subordinate was raised in effectiveness by the intelligence of the boss. The chief disadvantage was that the boss usually claimed too many of the benefits for himself. So began the " class struggle ", an attempt to distribute to the satisfaction of all the fruits of " vertical specialization ". It probably started when the first hunting boss claimed too large a share of the first co-operative mammoth. It is still with us.

These two principles working together can produce, and have produced, extremely elaborate civilizations. Horizontal specialization can develop until each individual performs only a minute task, at which he becomes very skilful. Vertical specialization has even greater possibilities. Hierarchies of bosses arise, from field foremen to Sons of Heaven. These support for their amusement, security, or profit all the ornaments of culture: philosophers, poets, artists, glittering generals, and priests.

Such were the ancient civilizations. The patterns of the cloth might vary widely, but the weave remained the same. Some were more military than others. Some were more commercial. Some wrapped themselves up in mystical flypaper. Some had tougher natural conditions to contend with. Some were harder to defend

from the comparative barbarians outside their borders. But they all depended upon a combination of the two types of specialization: vertical and horizontal. And sooner or later they all ran against the same blank wall which arrested their development if they were not destroyed ahead of schedule by some outside agency.

The limit, the blank wall, was the fact that the hand workers—slaves, coolies, or fellahs—could produce only a definitely limited amount of food and goods above their own minimum needs. This surplus could be increased only slightly by improved methods, by organizing the work, and by better hand tools. And on it lived all the upper grades of ancient society. The only way they could secure greater ease, luxury, and culture was by appropriating the surplus of more under-dogs. Sometimes this method was pushed to the limit, resulting in a minute island of luxury surrounded by a vast ocean of driven slaves. Such societies were apt to be unstable. In any case they could not develop further. There was nowhere to go. The ancient civilizations approached this limit with monotonous regularity. Then they fell apart like the Roman Empire or came to a halt like China and abandoned all hope of further progress.

But our modern civilization has battered a breach in the wall. We have done it by adding a third principle to " vertical " and " horizontal " specialization. Instead of merely dividing the work among ourselves, we have learned to create a low grade of artificial human being to perform the less intelligent tasks. Thus at one blow we have eliminated the obstacles which checked the upward progress of the ancient civilizations. Our synthetic slaves cannot revolt and make our structure unstable, and they do not press upon the food supply. Thus there is no limit to their number or to the amount of desirable goods or services they can produce.

These artificial slaves are, of course, power-driven machines. They are commonplaces in our society, and

we give them little thought except when some new and novel type is created. The earliest ones attracted little attention. Only recently have we begun to realize that a new kind of creature is sharing the planet with us. Civilization no longer consists of human beings alone, graded and specialized, but of human beings *plus* mechanical slaves.

The utter differentness of this step is well illustrated by analysing the functions of an isolated man supplying his own wants. His body, which is all he has, consists essentially of prime movers, the muscles. The power they develop is transmitted and transformed unto useful motions by an intricate system of levers and cables, the bones and tendons. It is directed by the brain sending messages through the nerves. The mechanical assembly amounts to an extremely versatile machine tool with a built-in power supply. It can do vastly more things than any artificial tool we have yet constructed.

But an independent human being is not merely a machine, however generalized. He is better compared to a factory full of machines *plus* the business office, the product designers, the salesmen, buyers, associated bankers, and other non-mechanical governing forces. He directs his own policy, which no machine or group of machines is able to do. He is intellectual as well as mechanical. He acts with judgment as well as with strength and skill.

As soon as civilization developed to any extent, this self-sufficiency of the individual was lost. Even in a social group consisting of free and equal specialists (horizontal specialization) there is no complete freedom of action. Each man has to adjust his product to the desires of the community he supplies. He may still use all the physical potentialities of his body. Some specialists do. But he delegates part of his judging powers to the group as a whole.

This effect was mild, almost nothing, compared to

what the invention of the Boss (vertical specialization) did to human independence. A boss is a person who does the thinking, or a part of it, for a group of subordinates. The bodies of the men may function as before, but the boss's brain supplies more of the judgment, intelligence, and experience. It doesn't matter if the subordinates have been enslaved, have "got jobs" or "accepted positions". The effect is the same. They will be acting more mechanically, using less independent judgment than before they had a boss. And the boss will be acting less mechanically and with more judgment than before he had subordinates. Vertical specialization tends to separate the mechanical from the intellectual functions of the human body and to concentrate the intellectual functions in the minds of a small number of bosses.

In the early civilizations, and in the first stages of our own, this type of specialization was carried to great extremes. Large masses of the population had their intellectual functions suppressed almost completely. The Roman galley-slaves, the Chinese coolies, the Egyptians who dragged the stones for the pyramids were not expected to contribute any intelligence whatever. Only their muscles were used by their masters. They were true "prime-movers", delivering their power in very simple forms, often a mere draw-bar pull.

The ancient civilizations did not consist wholly of such human motors. There were skilled workers of various types. There were soldiers, merchants, and civil servants. But most of the population earned its living by actually generating energy. That was the fate of man. They pushed, pulled, lifted, hammered. The measure of the average man's usefulness was the strength of his arms and legs. He was rated like a motor. The ancient civilizations consisted in effect of many sets of muscles working with little or no intelligence to accomplish the purposes of a much smaller number of brains.

This, of course, amounted to a great waste of human capability. Some men are more intelligent than others, but none are entirely stupid. A galley-slave pulling on an oar, a coolie lifting water may be doing what is necessary for the support of his social group, but he is not using his brain at all, and the thinking brain is all that raises man above the animals. Every man possesses intelligence capable of directing many sets of brainless muscles. To consider him merely a prime mover, a producer of energy, is to throw away the most valuable part of his ability.

That is what the ancient civilizations did and what modern civilization is learning how not to do. Instead, we throw away the man's muscles, or most of them, for we have found a vastly superior substitute in our various power-producing machines. This principle is the basis of our culture, the principle which the older civilizations refused to recognize or utilize. We don't know where it will take us. It may run us into trouble —has already. But it has enabled us to break through the upper resistance level of the curve of human affairs. We have entered new high ground. No civilization has been there before us.

Such is the rôle of power, the factor which differentiates modern civilization from all its predecessors.

When we try to set the date when mechanical prime movers began to replace human muscles, we find ourselves in difficulties. In the first place the ancient civilizations were not totally ignorant of such devices. The Romans and the Chinese, for instance, knew about water-wheels. They probably knew about windmills, too, although this is more doubtful. Boat sails, also, are true prime movers of limited utility.

But the point is that none of these things were used to any important extent. The ancient peoples had plenty of technical ability. They could have constructed very

effective power-producing machines. They did build amazing things for other purposes. The Roman catapults and aqueducts, the Chinese junks, the Babylonian irrigation works, the Inca roads were masterpieces of high engineering ability. But apparently it did not occur to any ancient people to build many artificial muscles. When they needed power, they merely found means of reducing the necessary number of human beings to prime-mover slavery. When the Romans wanted a fast ship, they did not improve their sails and rigging or invent steam engines to drive her. They preferred to capture slaves by warfare and chain them to three superimposed banks of oars. These galley crews were remarkable examples of discipline and training. No modern gangs could do their jobs. The ships were faster than anything up to comparatively modern times. But the galley-slaves were not human any more. Their minds, the finest parts of them, were wholly lost.

The practice of using human beings as mindless prime movers continued far into our own period. There were galley-slaves in the Mediterranean long after Columbus. Women towed canal boats in England until 1863. They still draw ploughs in Central Europe. They still load coal in Japan. All of these tasks can be done much better by mechanical muscles than by human ones.

In highly developed sections of the modern world, however, such human motors are extremely rare. A farmer may pump water for his stock, but he does it only a small part of the time. Lumberjacks develop a great deal of energy, but they also use much judgment. Certain factory workers—those who tighten " nut thirteen " on a motor-car assembly line—use little or no intelligence, but neither do they use much strength. They are transitional accidents. Most of them are being rapidly eliminated by machines or better planning. In many cases " nut thirteen " itself has been eliminated.

In the United States at least there are now very few workers acting as wholly brainless motors, and these have survived only in odd nooks and crannies in the industrial system.

The growth of power civilization was very gradual. It was not initiated by any single invention, certainly not by the steam engine, which came on the scene long after the use of power was well established in certain localities. The actual power had been available to Europeans for many centuries, for the knowledge of the Roman water-wheels was never entirely lost. We hear of them all through the Dark Ages, feebly grinding their grain on a few small streams. There are early rumours of windmills, too, although these were probably among the many valuable things brought back from the east by the Crusaders.

Northern Europe, the birthplace of power civilization, was not a highly developed region in, say, the tenth century. Most of the people lived on self-contained farms, supplied their own small wants, and rarely ventured more than a few miles from home except when invading their neighbours. Such a society required little power, even of the galley-slave type. The two kinds of specialization had not proceeded far enough to make human motors useful.

As Europe grew up and became more thickly settled, more co-operative, more unified ; as trade and industry increased ; we might expect to see the old slave pattern appear again in full force. But for some reason it did not do so. Perhaps the potential slaves forced their betters to respect their interests more than the Romans had. Perhaps there was some new quality latent in the minds of the north Europeans. At any rate, civilization branched off at some indeterminate date from the old, well-trodden path and tried another way.

When the Dutch, for instance, were confronted with their famous hydraulic problem, they did not resort to

slave-driven pumps, but built windmills. When the growing towns required large quantities of flour, they did not force many unfortunates to turn cranks, as the Romans had, but built more water-wheels. When trade demanded better ships, improved sails and rigging did the work of galley-slaves. It took many centuries to pass this fork in the road, but once past, there was no turning back. Civilizations may fall and start over again, but they never retrace their steps.

The extreme slowness with which the practice of using non-human energy became established was not the result of mere blind conservatism or the sabotage of vested interests, although these had their effects, as they always do. There was a deeper reason. Crude, raw power has very few uses. The power of human muscles is not crude. It is transformed by the built-in mechanism of the legs and arms into a large variety of useful motions. Not so with the power of windmills and water-wheels. They have to be hitched to some more-or-less complicated device before they can perform a useful task.

Since the beginnings of our civilization there has always been a surplus of crude power, ready and available. The rivers and streams of Europe were never completely harnessed although practical methods were known. The winds of Europe blew almost free. Water-wheels and windmills could have supplied vastly greater amounts of power if there had been work for it to do. But there was not. Power had learned to replace only the muscles of the dullest slaves. It could grind grain, pump water, run simple wood-working tools. Almost nothing else.

The development of our civilization from this point has consisted of *training* crude power, giving it arms and legs and skilful hands. As it became more skilful, we were able to delegate more jobs to it. In a sense we were solving an unemployment problem. The

muscles of non-human power existed in unlimited numbers. Potentially they were able to do much, if not all, of the physical work of the world. But they could not get to work before we learned to weave them into our lives in place of the muscles of the human body. Until then they were unemployed. What we call the power age had to wait for many centuries although the unappreciated prime movers pointed out clearly the road to a different, perhaps better, way of life.

The steam engine and the Industrial Revolution of the nineteenth century were comparatively late events in the civilizing process which I have been describing. The practice of using non-human prime movers to do useful work was well established long before the steam engine affected it in any way. And the Industrial Revolution merely marks the date when power machines had become sufficiently numerous to be noticed by the economists and phrase-makers.

There was certainly a connection between the steam engine and the Industrial Revolution. The practical steam engine was a startling innovation. It drew attention to itself, as the water-wheels, very numerous by then, had not been able to do. Thus its invention is said to have ushered in the Industrial Revolution, although in fact many of the characteristic power-using machines were in wide use long before it appeared.

The history of the steam engine is an excellent proof that more power always existed than could be put to useful work. The principle of the steam engine is very old. The æolipile described by Hero of Alexandria in 150 B.C. was a true reaction turbine. He seems to have understood the reciprocating engine as well, and the knowledge of both devices was never wholly lost. All through the Middle Ages we can find records of primitive steam engines. We would find more if more medieval mechanicians had been able to read and write.

These "engines" were of various types, but they all had one thing in common. They were all among the unemployed. They could do nothing which was not done far better by water-wheels, windmills, or by hand. Power-using machines were growing steadily in number and variety, but there was still plenty of water-power and wind-power for them all.

What was needed to bring the steam engine to the critical point of usefulness was a job which it alone could do. Finally such a job appeared: pumping out coal mines in the North of England. The mines were mostly open cuts, flooded by the rain as well as by ground-water. Hand pumps were too expensive to run. Horse-driven pumps were little better. Water-power was almost never available at the pit mouth, and wind-power was too undependable.

So for the first time steam was promoted from the notebooks of monks and philosophical gentlemen and put to work. In 1698 Captain Thomas Savery patented a steam mine pump. It was a vacuum affair with no moving parts, sucking the water into two egg-shaped copper tanks. It was fragile and not successful. Nine years later Newcomen put his reciprocating engine on the market. It also worked by vacuum, not by pressure, but it did the job. By 1711 it was standard in the coal regions, and it remained standard for sixty years.

At last steam-power had arrived! But nothing much happened. Newcomen's "water-forkers" pumped their water to the satisfaction of the English mine owners, but they were called upon to do nothing else. By this time power-using machines were multiplying all over Europe—lathes, saws, air compressors for blast furnaces—but they got along very well with nothing but the traditional sources of power. The first textile machines arrived in the seventeen-sixties (Hargreaves' card, 1760; and jenny 1764), but they were hitched to water-wheels,

not to the " water-forkers ". Even without steam there were still many more mechanical muscles available than could be put to work.

When James Watt started his experiments two generations after Newcomen, his only idea was to make a better pumping engine for coal mines. He had his eye on the " existing load ", not upon any " industrial revolution ". His first successful engine, built in 1773, was designed for the same old pumping job. For many years Watt remained convinced that steam-power was " too rough for milling ". Finally, in the 1780's, he was prevailed upon to equip his pumping engine with a crank, flywheel, and governor. Then and not until then was steam used for such simple tasks as grinding grain. It was as late as 1790 before it was attached to the new textile machines, although these had been in wide use for many years.

What had happened by that time was that power-using machines had become sufficiently numerous to press upon the supply of water-power. The eighty-year-old Newcomen engines could have been used for milling if they had been needed, but their crude power had remained unemployed because devices for transforming it into useful motions—machines—did not exist in sufficient numbers. Watt's engine came on the scene about the time more crude power began to be needed. Thus it got credit for starting the Industrial Revolution.

I do not want to appear to underestimate the importance of power. Its use is the fundamental factor in our civilization. But I want to make plain that we have always had more power at hand than we could employ. It was rough, unskilful power, however. It had to be tamed and trained before it could do useful work for us. Since the invention of the steam engine we have had an infinite number of unemployed mechanical muscles at our disposal. Our progress is measured

by how many of them we have found jobs for, and by how many useful things we have trained them to perform.

That's enough history, I think. Certainly enough for a book which intends to deal with those strands of our present life which reach out into the future.

But I wanted to explain the function of power very clearly. Its use is the only thing that makes us different from the Romans or the Egyptians or the Chaldeans. They *grew* their slaves by painful methods, or captured them from other painful growers. We *invent* ours with our brains, construct them of metal, breathe them full of " unnatural " life, and make them work for us without pay. Cæsar acquired, with the sword, three million Gallic slaves. The General Electric Company builds more than that number every year, and they are a great deal more useful than Cæsar's shaggy and murderous prime movers ever were.

Aristotle, like all respectable Greeks, owned slaves and benefited from their labour. He must have felt certain twinges of conscience, for in attempting to hallow the institution of human slavery he delivered himself thus: " If every tool when summoned could work of its own accord, as the creations of Dædalus moved of themselves or the tripods of Hephæstus went of themselves about their sacred work ; if the weavers' shuttles could weave of themselves ; then the master workers would need no apprentices, and the landlords would need no slaves."

This was correct at the time. The ancient civilizations could not exist without human slaves to free a few selected brains from drudgery. " No slaves, no civilization," was the fundamental principle of the ancient world.

But now our civilization rests upon a different base. The weavers' shuttles *do* weave of themselves. Instead of human muscles we use mechanical power. Every day it becomes more useful, more skilful, more bene-

ficial. Already, in the United States at least, we have many more mechanical slaves than human masters.

Their vital force is power. If we should run short of mechanical energy, our civilization would stop dead. So in the next section I am going to list our present sources of energy and estimate how much we have in store for future use.

FUEL SOURCES OF ENERGY

At present most of our energy comes from coal, both for power and heating. Coal will probably remain in the lead for years to come, in spite of growing competition.

It is an interesting exercise to estimate the world's coal supply. You can't lose, for no one can contradict you successfully. The most authoritative figures vary so widely and contain so many ifs and buts that no one need be afraid to join the game.

One thing is certain. The world contains a great deal more coal than we are ever likely to use. The Toronto Power Congress of 1913 set the "known reserves" at 7,400,000,000,000 metric tons. The World Power Conference of 1925 cut this figure to 5,855,000,000,000. A later estimate in the German publication *Technic und Wirtschaft* raised it again to 10,800,000,000,000. A fair average is something like 8,000,000,000,000.

These figures, of course, are practically meaningless. "Known reserves" include only coal deposits which have been discovered and measured. We do not know what lies beneath most of the earth's surface. There are probably vast unknown reserves of coal in such places as the Amazon valley, the interior of China, and Asiatic Russia. Even our own well-rummaged country surely contains billions of tons which the Geological Survey has never placed on its books.

The only thing proved by these astronomical figures is that our supply of coal is ample. During the prosperity

year of 1927 the world used 1,276,000,000 metric tons, which was only a small increase over 1913. Our present consumption is much smaller. At this rate the reserves *would last about 6,000 years.*

Of course consumption may increase. New uses may be found for coal. It may regain the ground lost to its competitors. But in no case is the supply likely to give out in less than a thousand years. And civilizations don't last as long as that. If ours breaks the precedent and does so, it will certainly find a better way to get its energy than by digging up fossil vegetation.

In fact we have already found a somewhat more convenient source of energy—petroleum, which is steadily encroaching upon almost all of the markets for coal and which now supplies about 20 per cent of the energy used by the world. It has two advantages over coal. It can be transported very inexpensively by pipelines and tankers, and its refined products can be used in internal-combustion engines of various types. The trend at present is strongly towards a greater use of petroleum in all its forms.

No one knows how much petroleum there is in the world, and even those who think they know won't tell. The oil business has become so fouled by commercial and nationalistic rivalries that none of the official estimates are worth serious attention. Oil companies keep their geological secrets to themselves. Nations with promising oil lands either exaggerate or minimize their possibilities according to the political weather in their vicinities.

Petroleum is by no means a rare mineral. It can occur wherever the underlying rocks were deposited by the sea, and this means most of the land surface of the world. Few countries are wholly without it, and these are largely crowded together in western Europe, a very small part of the world as far as area goes. It is safe to say that there are certainly a great many important oil fields remaining which have never felt a drill in their cover clay.

Estimates of the amount of available oil have been made from time to time since the first well was " brought in " at Titusville, Pennsylvania. They have had one thing in common. They were all too small. Every year they grew larger, but never fast enough to keep pace with the new supplies discovered. In 1927 the Geological Survey calculated that the American reserves would last eight years, until 1935. That deadline has now arrived, and at present the U.S. Government is greatly concerned with trying to keep domestic production from flooding the market with unwanted oil. The latest world estimate is something like 7,000,000,000 metric tons. In 1932 the world produced about 200,000,000 tons. At this rate the reserves will last about thirty-five years—even if no new fields are discovered.

They will certainly last much longer than that. Deep drilling is constantly finding new pools beneath the old ones. New methods of geological exploration are constantly revealing new fields. There are still large areas of the world which have not been investigated at all. The eastern slope of the Andes, for instance, is very promising. So are Central Asia and the Near East. We can use our oil with a free hand. We have hardly made an impression on it yet.

As a matter of fact, the oil reserves could approach exhaustion in the next few years without causing very much inconvenience. Ten years ago such an event would have been a disaster. Most motor-cars, for instance, would have been forced into dead storage. But in the last few years the situation has changed for the better. The hydrogenation process which turns coal into a liquid possessing most of the valuable properties of petroleum has made the possible failure of oil a very minor danger.

" Hydrogenation " is a formidable name for a comparatively simple chemical process. It was first applied to petroleum itself in order to get more petrol out of

the heavy crude. But recently it has been applied successfully to coal, and now artificial petroleum is waiting like an expectant heir for the death or decline of its natural parent.

Crude petroleum consists essentially of "hydrocarbons," compounds of carbon and hydrogen in various proportions. The lighter fractions, such as petrol and paraffin, contain less carbon and more hydrogen than the fuel oil and lubricating oil in the crude. All you need do to convert the heavy fractions into petrol is to make them absorb the proper amount of hydrogen gas.

Under sufficient heat and pressure, the large molecules of the heavy oils split into smaller fragments which contain the same number of carbon atoms as the light hydrocarbons in petrol. Simple division would leave these small molecules with too much carbon for stability. If no free hydrogen is present, this surplus carbon separates to form coke, as in the "cracking" process used largely in oil refineries. But if hydrogen is available under the proper conditions, it will combine with the extra carbon atoms of the heavy oils to form stable molecules of petrol.

Both of these processes, cracking and hydrogenation, are now used extensively in the oil business, and they allow the refiners to turn their crude into the particular product which offers the most profit. But only recently has hydrogenation been applied successfully to coal itself.

Coal has long been "cracked" to produce coke, tar, benzine, gas, and a long list of minor by-products which are very important in the chemical industry. But since coal contains a great deal of carbon and very little hydrogen, the yield of liquid hydrocarbons is small. Before coal can be liquefied, it is necessary to add practically all of the hydrogen which will be contained in the final product.

This can be done by the improved Bergius process, which has now reached a high point of technical perfec-

tion. The raw material is bituminous coal, although almost any type of coal will serve except anthracite, which contains too much free carbon. Brown coal or lignite is good. Even peat has been tried successfully in the U.S.S.R. The coal is first pulverized finely and then mixed with oil into a thick paste. This is heated under pressure in a retort, and gaseous hydrogen is bubbled through it. The result of the reaction is a complex mixture of hydrocarbons very much like crude petroleum from the wells.

The process sounds very simple, but an immense amount of research had to be done before it could be made to work efficiently. The reaction will only take place in the presence of the proper "catalysts" (substances which affect the reaction but do not form a part of the final product). The temperature, the pressure, and the relation between them have to be controlled exactly. And every type of coal acts differently in the retort.

The research has been done, however, and now the chemists can control very accurately the composition of the artificial petroleum. Coal can be made to yield as much as 31 per cent of petrol. Or the conditions can be varied to produce more heavy oil, as desired. The yields from 100 parts of coal by two typical processes are as follows:

Product.	Process A.	Process B.
Petrol	31·3	14·0
Middle oil	37·3	32·2
Heavy oil	5·0	32·2
Gas	23·6	15·3
Organic insolubles	3·0	3·0
Liquor	9·6	9·8
Hydrogen absorbed	9·8	6·6

The mixture of oils from the retort can be refined by distillation into its various fractions. The heavier parts can be used in Diesel engines and under boilers, or they can be hydrogenated further by the methods now used

in oil refineries. If this is done, practically all of the coal is turned into petrol.

At present the "thermal efficiency" of the process is about 45 per cent. This means that the heating value of the petrol produced is 45 per cent as great as the coal consumed, the difference being accounted for by the coal burned in generating the hydrogen and supplying the heat and power used in the plant. The efficiency will probably improve considerably, but it will never approach 100 per cent.

Hydrogenation of coal, as outlined above, can certainly be considered a complete technical success. It does what it is expected to do. But its economic status is not nearly so secure. Thus far it cannot compete freely with natural petroleum. At present the only hydrogenation plants built or under construction are behind tariff walls or subsidies. But the margin of safety for natural petroleum is not very large. Some idea of the comparative costs can be derived by the situation in England, where Imperial Chemical Industries Ltd. has constructed a large-scale hydrogenation plant at Billingham-on-Tees which will start operations this year.

Two years ago petrol could be landed in English ports for approximately 3½*d.* an imperial gallon. At that time the British government granted a subsidy of 4*d.* a gallon for nine years to Imperial Chemical Industries if it would erect a plant capable of producing 100,000 tons of hydrogenated petrol a year, approximately one-thirtieth of the domestic consumption. The fact that the offer was accepted proves that artificial petrol cannot cost more than 7½*d.* at the highest, allowing nothing for profit or possible scrapping of the plant at the end of the nine years. Since the I.C.I. is not particularly noted for its charity, we can safely assume that some margin was left for these items, bringing the probable cost down to perhaps 6½*d.* per gallon.

This leaves the cost of artificial petrol nearly double

the cost of natural petrol. On the surface the oil producers have very little to worry about. But actually the hydrogenation process is a very serious threat, for petroleum is not a normal commodity which is allowed to run freely in its natural economic channels. If it were the development of hydrogenation of coal would have to be postponed until the natural oil was nearly exhausted. But nationalistic considerations have intervened and promise to increase their influence in the future. There is a fairly good chance that natural petroleum may go the way of Chilean nitrates.

The parallel between petroleum and natural nitrates is surprisingly close. Before the war the only large source of fixed nitrogen was the *salitre* of northern Chile. About 80 per cent of the atmosphere consists of nitrogen, but there was no economic way to make it combine with other elements. It could be done in the laboratory, but the product was too expensive to compete in the open market. If non-economic factors had not taken a hand in the situation, natural nitrates would probably have supplied the demand until the deposits of *salitre* approached exhaustion.

But nitrates are the most important single raw material for a country engaged in modern warfare. All practical explosives contain fixed nitrogen in one form or another. The strongest military nation in the world is helpless as soon as its nitrate supply is exhausted.

In the years before the war Germany realized this only too well. So she supplied her best chemists with unlimited means for experimentation. The cost was tremendous, far too large to have been defrayed by any private corporation then in the field. But the results were more successful than anyone dreamed possible. Not only did the German chemists solve the problem of producing fixed nitrogen for war purposes. They actually learned how to make it almost as cheaply as the Chileans could scrape it off the ground. When the war

broke out and ocean transportation became uncertain, most of the other warring countries followed suit, including the United States. By the time the peace treaty was signed, so much had been learned about nitrogen fixation that the synthetic product has been able to dominate the market ever since. There is still plenty of *salitre* in Chile, but in 1932 it supplied less than 10 per cent of the world's needs. Natural nitrates will probably revive to some extent, but they will never regain their former monopoly.

Petroleum is now almost as important in war as nitrates were in 1914, and only two of the major nations, the United States and the U.S.S.R., possess an ample supply which cannot be cut off by a blockade. Great Britain, Germany, France, and Italy produce no domestic petroleum at all. Japan produces too little to make much difference in war-time. All these nations, especially Germany, have been experimenting with substitutes to take the place of petroleum in case of need. The result has been the perfecting of the hydrogenation process. At present it cannot stand on its own feet. But neither could synthetic nitrates in 1914.

If a general war should start to-morrow, it is practically certain that hydrogenation of coal would leap into sudden prominence. But even if war does not come, the synthetic product will probably creep up slowly with the aid of subsidies to a position where it can compete honestly with natural petroleum. The oil reserves of the world are nowhere near exhaustion, but the tendency is for the cost to increase. Oil from deep wells or from remote countries is inherently more expensive than oil from the convenient sources we are tapping to-day. Coal, on the other hand, is not seriously affected by such considerations. The present sources of supply are practically inexhaustible, and the cost of extraction is constantly falling as more machinery enters the mines.

So hydrogenation is a " tool of to-morrow " which is

worth watching. It was born of the evil parents of nationalism and war. At present it is supported by tariffs and subsidies. But even if the world takes the pledge of eternal peace and brotherhood, which is not likely, hydrogenation will always stand ready to replace natural petroleum as soon as the price of the latter increases a few cents a gallon. Hydrogenation is the link between the comparatively small reserves of oil and the practically inexhaustible reserves of coal. Before the process was developed, petroleum was indispensable. It could do various things which coal could not do. But now natural oil may be considered merely the cheapest liquid fuel. As soon as it becomes a little more expensive, liquefied coal will take its place. The motor-cars and aeroplanes of the next century (if they are still driven by heat engines) need have no fear for their power supply.

WATER-POWER

Water-power sounds like an exciting subject. It is, too, in a way. There is nothing more complete and perfect than a modern hydro-electric plant. Everything is clean, balanced, and regular. The river rushes through the turbines with a low, domesticated roar. There is no confusion, no hurry, no escaping steam, no sense of alertness against impending disaster. All the possible dangers have been foreseen long since and provided against.

Such a plant is a glimpse of the future. There are very few men in sight, and almost all of them do work of a very high type. They watch innumerable gauges, dials, indicators. They check bearing temperatures, watch lubrication, communicate by telephone with distant points. They operate vast switches and motor-driven water-gates. They hardly use their muscles at all, only their brains.

Here we see nature under perfect control. Here we

see men freed almost completely from the necessity of generating muscle-energy. In most factories and other industrial establishments there are ragged edges. In the midst of an orderly tangle of highly automatic machines, men still lift weights, perform monotonous hand-labour, clean up débris. There are noise, vibration, periods of confusion and doubt. All of which are sure indications that perfection has not been attained.

But not here. Hydro-electric plants are probably the most finished achievements of industrial civilization. They have certainly approached most nearly to the end-point of absolute efficiency. Some day they may be replaced by another and better way of generating power, atomic power for instance, but there is small chance that they will be much improved. There is too little room for improvement.

This very perfection robs the future of water-power of much of its interest. The turbines, for instance, are already 94 per cent efficient. The generators are even better. The controls and switching gear are somewhat ponderous and dangerous still, but they are comparatively minor factors in the plant itself. They belong to power distribution rather than to generation.

The dams, diversion tunnels, and other means of handling the water are practically perfect, too. We may learn how to construct them less expensively, but already the engineers are prepared to build any dam conceivable. They would dam the Grand Canyon of Colorado at its deepest point if given sufficient funds.

The technical problems of how to generate water-power are solved. The remaining problems are economic, social, and political. Hydro-electric power is waiting for us when we want it, *if* we want it. The future depends upon tariff, world trade, the wages of coal miners and similar factors out of the control of the men who design turbines and dams. Their pioneer work is done.

Nevertheless, it is rather interesting to take a look at the vast amount of water-power we can gather when we want it. There are no definite figures available—certainly none which should be trusted. Potential water-power is not a tangible thing like coal or petroleum. It cannot be measured apart from the economic and other factors which affect its possible development. Therefore it cannot be measured accurately at all.

The total theoretical water-power in the world is an immense figure which might be computed by estimating the amount of rain or snow which falls on the surface of the land and multiplying its weight by the vertical distance it has to drop before it reaches sea level. This has never been done to my knowledge, and there is no use doing it. The world will never become so power-thirsty that we shall have to run little pipes to every mountain-top.

Before this theoretical outside figure come various more conservative estimates, but none of them mean very much. A particular river, let us say, gathers its water at various levels up to 4,000 feet. It contains one sharp fall 50 feet high, a number of steep rapids, and many long, smooth stretches between. Some of its branches are mountain torrents. Others are sluggish streams draining flat plains.

The potential power of this river will depend on a number of factors besides the amount of water flowing and the height of the drop. The cataract can be developed easily and cheaply by diversion canals. Its power will certainly figure in the total. The same in less degree will be true of the steeper rapids. But these will account for only a small part of the river's total power. Some stretches will have too gentle a drop. Some sections cannot be dammed without flooding valuable farm land. Others, running through wide, flat valleys, cannot be dammed at all. The same will apply to all the branches, big and little.

Somewhere between the " cheap power " of the cataract and the " theoretical total energy " of the rain falling on the heights will lie the figure for the " potential power " of the river. No two engineers would agree where to put it. Some would insist that " potential power " means power which might be developed with good hope of profit. Others, not so commercial, would include all the dams which might be built on the main stream and a few on the branches. If the river valley contained a larger number of industries, and if the cost of fuel was high, it might be justifiable to include small stations using long penstocks starting high up the sides of the mountains, as in Switzerland. The smallest of these estimates might be as low as one-tenth of the largest, but each would be a perfectly legitimate view of the " potential power " of the river.

The same principles apply to all rivers big and little. To say that the " potential water-power of the world is 380,800,000 horse-power according to one estimate, or 1,483,000,000 horse-power according to another, means merely that the engineer making the estimate has picked a certain arbitrary point to stop. He might have gone farther or stopped sooner without increasing his chances of error.

The fact is that water-power is valuable only when it can compete commercially with the cheapest fuel available at the nearest point where it can find a market. This rules out for practical purposes the noblest cataracts in the eastern Andes. And it also eliminates many sites near coal fields, oil wells, or sources of natural gas.

There are so many factors, which affect the competition of water-power and fuel-power that every separate project is a special case. The chief advantage of water-power, of course, is the fact that its energy supply costs nothing. This is counterbalanced by the generally larger carrying charges of the dam or diversion works. In typical steam plants the " fixed charges " amount to

about $\frac{1}{15}d.$ per kilowatt-hour when the plant is in operation at full capacity all the time. The figure for Boulder Dam will be about $\frac{1}{5}d.$ under the same conditions. Steam plants have to pay an additional $\frac{1}{5}d.$ for fuel besides larger labour costs. But Boulder Dam power will have to go to market over long transmission lines, whose cost has not yet been determined.

These are only a few of the factors affecting the competition of steam and water. The costs of a steam plant are much reduced when the plant is shut down. The costs of a hydro-electric station go on just the same. On the other hand, steam plants have considerable maintenance costs, while hydro stations last practically for ever without important repair or replacements.

On the whole, it only pays at present to skim the cream off the water-power supply, to use the favoured sites which may be developed cheaply. According to the Geological Survey there are 32,000,000 kilowatts of water-power available in the United States which could be developed for less than £100 a kilowatt. This compares with the 11,800,000 kilowatts already developed. In the United States in 1933, hydro plants developed 41 per cent of the power of central stations. In the world as a whole the percentage is much lower, but the potential power, including the power sites in remote countries, is much larger in proportion.

About the future of water-power utilization the authorities are cautious but rather united in their optimism. Two important factors are at work to favour "white coal" in its competition with fuel. The first is the constant improvement in transmission methods, which will have the effect of bringing remote power sites nearer to their markets. If high-tension direct current or radio transmission of power are ever developed, moderately distant rivers will certainly be harnessed, such as those of the Canadian Rockies, Labrador and Maine.

The other factor, probably more important, is the steady growth and vast possibilities of the electro-chemical industries. These amount in effect to large portable markets for power. The most important for the future is probably the electrolytic reduction of Aluminium. It takes 12·5 kilowatt-hours of electricity to produce one pound of the metal, or 25,000 kilowatt-hours per ton—as much as an ordinary household uses in ten years. The ores of aluminium are very common and well distributed. Therefore, as the demand for the metal increases, we shall probably see the industry seek favourable power sites in comparatively remote localities, eventually reaching the eastern Andes and Central Africa, where large amounts of water-power are running to waste.

Other electro-chemical industries are magnesium reduction, the fixation of atmospheric nitrogen, and the manufacture of abrasives. All these tend to gravitate towards sources of inexpensive power. Their raw materials exist in abundance in most countries. Their products are comparatively valuable per pound and can stand large transportation charges.

At present the prize exhibit of this effect is Norway, which owes most of its industrial existence to the cheap water-power which it employs in this way. But if tariffs and other barriers to trade do not increase, we shall certainly see electro-chemical plants using the inexpensive power of remote, mountainous countries such as Chile, Alaska, and Brazil.

TIDAL POWER

In the preceding pages I have discussed the sources of power which are in general use at the present time: coal, petroleum and river water. They will probably continue to dominate the field for a long time to come. But no discussion of power would be complete without

at least touching on the sources which we may use when our requirements increase, as they certainly will. Some of these are old, some are new. Some are hesitating on the very edge of practicality. Some are little more than laboratory speculations.

The new source of energy which is at present nearest to practical utilization is undoubtedly tide power. There have been tide-mills in the past and a few are still in operation. A small tide-power mill has been grinding spices in Boston for more than a century, supplemented now by electric motors. But these are all holdovers from the days when more constant prime movers were not available.

The trouble with tide power is its intermittency. No matter how high the rise of the tide, there is always a dead period while the flow is changing its direction. The height of the rise also varies in a monthly cycle of spring tides and neap tides. Before tide power can become suitable for modern purposes some method must be found to smooth out these fluctuations and provide a more or less steady flow of power.

There are three practical ways of going about this. The simplest is to connect the tidal station with a superpower network. While the tide is running full, the steam plants belonging to the system would be closed down, or the river-power plants would be accumulating water in high-level reservoirs. When the tide is slack, its load would be carried by these other generators.

Technically this system is excellent, but there are economic obstacles. The chief cost of a tidal station is the dam or "barrage." This will cost the same no matter how much of the power is used. Therefore all must be used while the tide is running. This will require turbines and generators capable of developing the whole of the available power in a small part of the day. The rest of the time they will stand idle, eating their heads off in carrying charges. The same will apply to

the steam or hydro plants replaced by the tidal power. Each unit will have a very small " load factor ", which is poor practice in the power business.

The second method is " pumped storage ", and is a great deal better from a practical point of view. Such a station would consist of a barrage thrown across a narrow estuary. Part of the power of each ebb and flow would be sent direct to the transmission lines. The rest would be used to pump water into an elevated reservoir in the hills near by. While the tide is changing and so yielding no power, this water would run back through the turbines and keep the current flowing.

Such " pumped storage " systems are rather surprisingly efficient. The water is raised by electric motors operating centrifugal pumps. These same pumps can be used as turbines to turn the same motors as generators. They can smooth out the fluctuations in the power curve to any desired degree. Their efficiency is about 61 per cent, which means that they get 61 kilowatt-hours back for every hundred expended. The station as a whole would do much better, for only a very small part of the power, depending on local conditions, would have to be stored in this way. If the reservoir were large enough, it would also take care of the monthly fluctuations of the tide.

The third system, and probably the best where it can be used, is that of " multiple reservoirs " at sea level. The tide, instead of flowing back and forth through turbines in a single barrage, will circulate between the open sea and two connected " polders ". While the water is flowing into the first, the second will be kept empty. When the tide is turning, the water will flow from the first polder to the second. And when the tide is sufficiently low, the water will flow from both polders back to the sea. By nice calculation, such a system can be made to yield a steady flow of current which fluctuates only monthly with the height

of the tide—a much less serious matter than complete stoppage four times a day.

The theoretical total of tide power has never been estimated accurately. It is very large, certainly larger than all the river power in the world. But tidal power plants are even more limited by local conditions than river plants are. In the first place there are comparatively few coasts on which the tides rise very high. The general average over the whole earth is a matter of inches. Only when the tidal bulge is concentrated by converging coast-lines does its size become really impressive. Such conditions exist on many bays with wide mouths—such as certain waters around the British Isles, the Bay of Fundy, the Gulf of California, and the mouth of the Orinoco. Unfortunately, most of these places happen to be rather remote from markets for power. The best are the Bay of Fundy and the Severn Estuary on the west coast of England.

The depression has put a stop for the last three years to practically all large power projects except those financed by governments for social purposes. There is already more power available in most localities than can be absorbed under present conditions. But before the curtain of pessimism fell, two tide-power projects were under investigation. Authoritative government figures are available for one of them. They look very good indeed.

The Bristol Channel on the west coast of England is a funnel-shaped bay which narrows to a sharp point and forms the mouth of the river Severn. Just above Bristol is a narrow constriction locally called "The Shoots", through which the tide boils like a mill-race. "The Shoots" are only 1,500 feet wide and 60 feet deep. They could be dammed easily. Above them is sufficient space for a daily storage reservoir.

In 1925 the government actually appointed a distinguished committee to investigate the possibilities of

this site. With characteristic British deliberateness it took eight years to make its report, but it proved that the tides of the Severn would yield one-eleventh of the total power which England would need by 1941 and would do so at a cost much lower than for a similar steam installation.

According to the recommendations of the committee the Severn Barrage should be a pumped storage station. It would consist of a dam across "The Shoots" and a reservoir eight miles away in a small valley some 500 feet above sea level. This would hold sufficient water to "smooth out" both the daily and the monthly fluctuations.

The annual net power produced would be about 1,610,000,000 kilowatt-hours, about 38 per cent of what is expected from Boulder Dam. The total cost of the project would be £50,000,000 including harbour, rail, and road works, plus a liberal contingency-allowance of 12½ per cent. Each kilowatt-hour would cost ·2372*d.* as compared to the average cost of ·375*d.* for steam power in England. Transmission lines would cost very little, for the plant would be only a few score miles from its market.

Nothing is being done about this project at present. England hasn't got the £50,000,000, and the government doesn't relish throwing any more coal miners out of work. But there is nothing wrong with it, technically or economically. If England decides that she needs the power, finds the money and the courage, we shall see the tides of the Severn running the industries of Birmingham and Oxfordshire.

In the United States the only tidal power location which has been studied in detail is that on the Bay of Fundy near Eastport, Maine. This has the disadvantage of being rather far from existing markets, but local geography makes it ideal for a station of the multiple-reservoir type. The tidal rise is in the neighbourhood

of 25 feet, and there are several natural bays which could be used as ready-made polders.

Reliable government figures about this project are not yet available. The Department of the Interior is planning a detailed survey, but has not yet acquired the funds from Congress. The estimates of various promoting groups are rather too optimistic to be trusted blindly. There is no doubt that the plant would produce a tremendous amount of steady, dependable power. So much is certain. The only obstacles are economic and political. Maine already has more power than she can use. Transmission beyond the state boundaries is forbidden by law. A treaty with Canada would be necessary, and this has been held up by local interests which fear that the plant would damage the fisheries in the Gulf of Maine.

On the whole, tide power is rather in the class of second-grade river power. There are no technical obstacles to its utilization, but the time is not ripe. Improved transmission methods would help it. So would new electro-chemical industries. So would a rise in the price of coal caused by improved social conditions in the coal fields. We don't need the tides yet, but they are one more assurance that our machines will never suffer from a power famine.

VOLCANIC POWER

Besides the tides we have one more novel source of power which has already passed beyond the stage of speculation. This is power from the internal heat of the earth. We don't know where it came from or how much there is of it. But we suspect that there is enough energy below the earth's crust to keep our present industries going for at least a million years.

The earth used to be considered a ball of molten material surrounded by a thin shell of solid rock. This

is no longer believed, but we do know that the interior is extremely hot. In most places the heat is a long way down, the temperature increasing only a degree or so for every 50 feet. But often the "magma", or hot material, actually reaches the surface to form volcanoes, or comes near enough to meet water and produce geysers, hot springs, and other thermal effects.

Sir Charles Parsons, the inventor of the steam turbine bearing his name, made a fascinating suggestion some years ago. He proposed to excavate a shaft 12 miles deep and even worked out some extraordinary methods of working in the hot rock he expected to encounter. The primary motive was to learn more about the inner make-up of the earth's crust, but he was confident that such a shaft would produce tremendous amounts of power.

It is not considered likely that such would be the case. Heat moves slowly through rock. The amount of energy which could be extracted by pumping water down the hole would probably be large, but strictly limited and insufficient to pay the astronomical costs.

It is not necessary, however, to go to such trouble. There are plenty of places in the world where the hot rocks lie only a few hundred feet below the surface, and some of them have natural supplies of water which gather heat from large areas underground. Vents of volcanic steam exist in Java, Japan, Italy, New Zealand, and both North and South America. Their utilization is a possibility no longer. It is a practical accomplishment on a small scale, and will probably be a minor but interesting factor in the power economy of the future.

The best work by far has been done in Italy under the direction of Prince Ginori Conti, one of the country's leading industrialists. In Tuscany, a few miles back from the coast, is a district some ten miles square which abounds in boiling springs, locally called "*lagoni*". They were formed by natural steam escaping from the

ground and excavating cup-shaped cavities which filled with condensations and rainwater. As early as Roman times they were famous for their medicinal qualities, largely imaginary. Lorenzo the Magnificent made many pilgrimages to Maremma to cure his gout.

The *lagoni* were first used commercially for the extraction of boric acid. At first the water was merely drawn off and concentrated over wood fires. But in 1827 François de Larderel had the brilliant idea of covering the springs with brick domes to capture the steam for heating evaporating pans. This process worked so well that Tuscan boric acid dominated the market for fifty years until crystalline deposits were found in the United States and elsewhere. This is the first recorded instance of the commercial use of the energy of volcanic steam.

When Prince Conti, a son-in-law of a descendant of the original Larderel, took over the management of the business just before the war, he was at once struck with the possibilities of this source of energy in a country lacking coal and oil. Italy has a large amount of hydro-electric power, but it is highly seasonal and much of it has to be sent to market over long and wasteful transmission lines.

The Prince found that harnessing his ready-made steam was not as simple as it seemed. In the first place the steam came from the shallow wells then used at very low pressure, three to four pounds. This made it necessary to use condensers or lose three-quarters of the energy available. But the volcanic steam contained, besides the boric acid, about 6 per cent of non-condensable gases, mostly carbon dioxide and nitrogen—enough to spoil the vacuum of the best condenser.

This difficulty was met at first by using the natural steam in an ordinary boiler to produce clean steam for the turbines. But efficiency was low and the equipment was complicated and expensive. The next step was to drill wells into the steam-bearing stratum itself, which

lay not more than 200 feet below the surface. This was not easy, as can be imagined, but was finally accomplished by special methods developed for the purpose. The results were striking. The steam blew out like gas from an oil well. The early shallow wells had been called "*suffioni*" from the hissing sound they made. But the workmen promoted the new deep wells to "*suffionissimi*". Their roar could be heard a dozen miles away.

The *suffionissimi* had not only a tremendously larger volume, but their pressure rose to about 60 pounds. This allowed the steam to be used in non-condensing turbines without serious loss. Only the most troublesome impurities had to be removed to prevent corrosion and other difficulties.

At the present time the volcanic steam of Tuscany is generating 14,400 kilowatts of steady and dependable power, some of which is sold to the State Railway system. More developments are under way. There seems to be no immediate limit to the power which may be obtained. New wells do not reduce the pressure or the volume of the old ones in the slightest. The output does not fluctuate at all. And the impurities in the steam are mostly valuable compounds which more than pay the cost of their removal.

There have been several attempts outside of Italy to use volcanic energy. These are successful, although on a small scale. At Geyser, California, there is a small plant, and hot springs heat the houses of Reykjavik, Iceland, through long insulated pipelines.

On the whole, volcanic energy looks very promising. Regions of mild volcanic activity are not rare by any means. Most thermal springs would probably yield steam if drilled to a moderate depth. And as we learn more about the interior of the earth, we will probably find other suitable areas. Steam springs and fumaroles are merely accidental indications, like oil seeps, of what

lies below. Development at present is held back by the fact that most volcanic regions happen to possess ample supplies of water-power. When this becomes insufficient, we shall probably see New Zealand, Japan, and other similar countries turning to the power of the magma beneath their boiling springs.

WIND-POWER

Wind-power has been known for thousands or years. Probably the first power used by man was captured by the sails of boats. Windmills, too, are very old, originating probably somewhere in the East. Thousands are working still, of course, but they have been largely reduced to that simplest of power tasks, the pumping of water in small quantities.

The trouble with wind as a source of power is its undependability. Unlike the tides, whose behaviour can be predicted with absolute accuracy, the winds are fickle things. Only in a few places do they blow constantly. And most of these favoured places, the West Indies for instance, have little use for power.

Nevertheless, a great deal of effort has been expended upon utilization of wind-power. Experiments are still in progress, notably in the Soviet Union. But conservative engineers for the most part remain unimpressed. Wind will do wonders while it is blowing, but it seldom blows hard enough or long enough to run a serious power plant.

Experimentation at present is proceeding along two lines. The first is the conventional windmill, much improved by modern knowledge of aerodynamics. A windmill vane is an aeroplane wing reversed. The wing moves through the air horizontally and causes a stream of air to flow downwards, which supports the wing by its reaction. The vane does just the opposite. It intercepts a stream of air and extracts fiom it power

for motion at right angles to the flow. Therefore, allowing for differences of speed, the same aerodynamic laws apply to both the wing and the vane.

The vanes of the windmills used at present are flat planes or slightly curved sheets of metal. They are extremely inefficient. The wind-motors of the future, if they ever come into use, will have vanes like the wings of an aeroplane : thick, curved on both sides, with blunt leading edges and sharp trailing edges.

The best recent work along these lines has been done by the Soviet Government, which has created a " Wind-Power Institute " for the purpose. It is particularly interested in developing a supplementary source of power for use when the rivers freeze up in winter. Some parts of the Soviet Union have unusually strong winds of fair constancy.

This is notably the case in the Crimea, and here the Institute has conducted its principal experiments. The latest mill is an 80-foot tower carrying a wind-motor some 90 feet in diameter. It has three vanes built of wood and metal and covered with sheet steel. They are like aeroplane wings in section, about 27 inches thick at maximum and tapering from 6 feet wide at the hub to 3 feet at the tip. Their pitch can be varied like the blades of an adjustable propeller. This is done automatically by means of a centrifugal device, and it keeps the speed constant in varying winds. One of the chief disadvantages of conventional windmills for generating electricity is that variations of speed yield uneven voltage or frequency.

This Russian mill seems to have been designed with great skill and ingenuity, but its performance is not impressive. After a year's operation it proved that it could develop 100 kilowatts when the wind was blowing 23·5 miles per hour, which it seldom does. In a year the plant produced only 200,000 kilowatt-hours, which proved that it ran on the average at less than quarter

capacity. If generated by an efficient steam plant this amount of power would cost about £280. The results are not nearly worth the labour and expense of the apparatus. Soviet Russia has plenty of coal, oil, and other sources of power. So it is not likely that Russia's winds will be harnessed by such methods.

The other method, the Madaras wind-rotor, doesn't look very promising either. The Madaras plant works on the well-known "magnus effect" which Flettner used in his rotor ships some years ago. The principle is simple. If a cylinder is revolved rapidly, it drags a certain amount of air around with it by "skin friction". A wind blowing at right angles to the axis of the cylinder will cause the revolving layer of air to pile up in a pressure area on one side and, similarly, will form a partial vacuum on the other. The difference of pressure between the two sides will result in a "translational force" upon the cylinder at right angles to the wind.

Flettner used two of these rotors to propel his ship across the Atlantic, which they did with a good deal of help from Diesel engines. Madaras proposed to place his rotors on land ships, trucks with flanged wheels moving on a circular track. The power would be developed by suitable generators attached to the axles. The cylinders would have to reverse their direction of spin twice in each trip around the track, and they would develop no power when moving parallel to the wind.

One of these rotors was actually built full-size, 90 feet high and 28 feet in diameter, of steel and corrugated dural. It was placed on a circular track 3,000 feet in diameter with rails 30 feet apart, and at the time of its announcement, it was expected to develop 1,000 kilowatts of net power at favourable wind velocities. The cost was estimated at £8 a kilowatt for a 40,000-kilowatt installation.

That was in the autumn of 1931. Nothing much has

been revealed since then except that Madaras himself reported the findings " decidedly satisfactory ". The cylinder, he said, revolved with a peripheral speed of 50 miles an hour and developed a " translational force " of 8,000 pounds in a 10-mile wind. These figures mean little. It would take a prophet to turn them into " net kilowatts ". Nothing is said about how much power was used up in turning the cylinder, reversing it, and propelling the apparatus around the track.

It is safe to say that the Madaras plant has not been successful so far. In this it resembles all other wind-power projects. Small improved windmills of the conventional type will probably be used in remote locations for some time to come, but on the whole wind-power is one of the least promising sources of energy for the future. Its undependability runs counter to the whole spirit of modern technology.

SOLAR POWER

All the energy we use at present comes from the sun, with the exception of the small trickles we now derive from the tides or the internal heat of the earth. Why not use it direct, instead of waiting for the sun's rays to fix carbon (coal, oil, wood) for us or to raise water for hydro stations or disturb the atmosphere for windmills ? A great many people have been struck by the possibilities of this obvious idea. The figures are impressive. The radiation falling upon one square yard of the earth's surface is roughly equal to one horse-power. On an acre, to 4,840 horse-power. The total radiation intercepted by the earth is equivalent to 200 trillion tons of the best coal per year, 200,000 times as much as we consume to-day.

Many experiments have been made and a great deal of money spent on this problem. The usual method is to concentrate the radiation by means of mirrors upon

a black boiler and use the steam in a conventional engine. All these devices work, but none of them work well enough to be taken seriously. At present a few are in operation—in Egypt and other favourable locations, but they are maintained by cranks or by freaks of local patriotism. They could all be replaced economically by ordinary heat engines.

Solar power has many fundamental disadvantages. In the first place it is both periodic like the tides and in most places undependable like the winds. At night there is no power available except at the Poles in summer, and the Poles are poor places for power stations. During the day, even, the power is not steady, but rises and falls with the height of the sun above the horizon. The seasons have their effects and so do the changes in the actual amount of radiation arriving from space. In most countries there are some clouds more than half of the year. Even regions without rain are affected by occasional clouds, haze, or dust in the upper atmosphere.

Besides these unavoidable disadvantages, the solar steam plants are extremely inefficient. The mirror-and-boiler combination has probably been built as well as possible, but the best efficiency claimed is 25 per cent. The actual figure is probably nearer 10 per cent. The steam pressure must be low, for high pressure requires high temperature and consequent re-radiation from the boiler. Low-pressure engines are always inefficient.

So the theoretical one horse-power per square yard diminishes rapidly to a very small figure. Leaving clouds out of the calculation, the daily fluctuations reduce the average power available to about ·2 horse-power for each hour in the twenty-four. If efficiency is 10 per cent, this is further reduced to ·02 horse-power. So a thousand horse-power plant would have to cover 10 acres, in a cloudless country at the equator.

This vast amount of apparatus would replace only a small part of the conventional steam plant. The ex-

penses for engine, generator, etc., would be as great as before. They would be larger, in fact, for low-pressure steam requires large, slow-moving machinery. The only saving would be the fuel, a few tons of coal a day, the cost of which would not equal the labour expended in dusting the mirrors alone.

There is only one hope for solar power, and it is a faint one. Knowledge of photo-electric effects is increasing rapidly. Some day a cell may be developed which will transform nearly all the radiation falling upon it directly into electric current. It is not too much to hope, considering the speed with which this branch of technology has been moving in the last few years.

Such a plant would have certain possibilities. It would need no boiler, turbine, or generator. It would have no moving parts, a feature which always appeals mightily to engineers. It would still be subject to the inherent disadvantages of solar power, but might be useful in certain favoured regions and for certain limited purposes.

This is a very distant possibility, however. Photo-electric cells to-day produce only microscopic amounts of current and are extremely expensive. On the whole it is safe to say that solar power is not promising.

MINOR SOURCES OF ENERGY

Various other sources of energy have been proposed. None of them look very good at the moment, but they should at least be mentioned.

The first is energy from alcohol distilled from fermented sugar cane, corn, or other vegetable material. There is nothing theoretically wrong with this idea. Alcohol can be used in ordinary petrol engines with good results. The only trouble with it is the fatally high cost. It contains much less energy per gallon than petrol and under normal conditions it costs several

times as much to produce. It cannot compete at present even with motor fuel made by the hydrogenation of coal.

In certain sugar-growing countries, such as Cuba and Brazil, a small amount of alcohol is used as motor fuel. It is made from blackstrap molasses, the residue of sugar refineries, which is too plentiful to be used locally in any other way. Even so, the alcohol has to be aided by heavy duties and subsidies before it can compete with petrol on a price basis. The laws favouring its use are nothing more than indirect ways of subsidizing the sugar growers.

Tropical agriculture could doubtless produce enough alcohol power to run all the industries of the world. There are no technical obstacles. But unless the present craze for nationalism reaches new heights of absurdity, it is not likely that such power will be used to an important extent, even in countries with sugar surpluses.

Another rather visionary scheme is the ocean-water power plant designed by Georges Claude, the inventor of the neon lamp. In the tropics the temperature of the surface water often reaches 80 degrees while the water in the depths remains only a few degrees above freezing. Any temperature difference can be made to yield power, and this one is no exception to the rule.

Claude's idea was to sink a long pipe into the sea and draw the cold water into a condenser. This would form a partial vacuum in a boiler containing warm surface-water. The warm water would boil, yielding low-pressure, low-temperature steam which would run a turbine between the boiler and the condenser.

There is nothing theoretically wrong with this idea. It works on a laboratory scale under favourable circumstances. Claude actually spent more than a million dollars building a plant in Cuba, but the power yield

was not sufficient to move the vast volumes of water and pump the dissolved air out of the condenser. Improved apparatus may some day give better results, but no competent engineer seems to think so at present.

A few years ago oil-shale was much discussed as a future source of power. It has never been used except on an extremely small scale, for the cost of separating the oil from the rock by distillation was far too high, but it was regarded as an inexhaustible reserve which could be drawn upon when the natural petroleum gave out.

Now it is considered unlikely that shale will ever be used in serious amounts. When the oil gives out at some distant date, we can turn to the hydrogenation of coal, a much cheaper process than distilling shale. Not until the coal is gone also will we be forced to use oil-shale, and by that time we shall probably have much better and more convenient ways of securing energy for our machines and vehicles.

ATOMIC POWER

One more source of energy remains to be discussed, if the word " discussion " may be applied to a possibility about which we know so little. This is atomic energy. We know such a thing exists, but we haven't learned how to obtain any of it yet. If we ever do, the discovery will certainly be more important than any we have made since the first primitive technician designed the first stone tool.

At present the whole science of higher physics is in a state of complete and unprecedented confusion. Nearly every important point is controversial. Nearly every fundamental law is disputed by competent authorities. There is no boundary between physics and mathematics, and hardly any between mathematics and

philosophy. Certain physicists have begun to preach lush religious mysticism from the austere pulpits of their laboratories. Frightened by their own confusion, they whisper desperately that perhaps free will is functioning somewhere deep in space—or even that the material world is governed by the whims of a God or Demon.

This attitude, of course, is surrender, and although it is very pleasing to priests and others not over-friendly to science, I do not think it will last long. Sooner or later some calm, stupendous person will reconcile the apparently conflicting facts, gather "the expanding universe", "curved space", and the troublesome "quanta" into one shapely theory, and set the wheels of science on their rails again. Such a man will rank far above Newton. He has not appeared yet.

Until he does, there is no use trying to outline in a few words what is known about the atom and the energy it may be forced to yield. The best I can do is point out a few facts which are generally accepted as such.

The structure of the atom cannot be described in ordinary language except by an exceedingly rough analogy. No one has ever seen an atom or an electron. No one expects to. They are both infinitely smaller than the light waves with which we see. They make themselves known only by their effects. Thus when we say that an atom is a miniature solar system, a proton-sun surrounded by electron-planets, we mean that it acts in some respects as if it were. The electrons are not little balls or even little rings like the rings of Saturn. They are not matter at all. Perhaps they are "points of stress" in space, whatever that means. We do not know if it means anything. Some authorities say it does not.

The solar system analogy, however, will have to serve us here. We may imagine an atom to consist of a nucleus surrounded by electrons moving on orbits like

the earth and the other planets. The number of electrons is proportional to the "atomic number" of the material. Hydrogen has one electron per nucleus. Helium has two. Iron has twenty-six.

These electrons move exceedingly fast, revolving on their orbits several thousand million million times per second. The orbits are very small, of course, but the actual speed of the electrons is measured in hundreds of miles per second. This is much faster than any rifle-bullet, much faster than the earth's speed around the sun. It is exceeded only by such figures as the speed of light.

Thus every atom is roughly the equivalent of a small flywheel spinning much more rapidly than any full-sized wheel will ever spin. An engineer whose job is designing high-speed machines would expect such things to explode. Some of them do—occasional atoms of the radioactive elements. But they explode at a very deliberate rate which we cannot hasten in any way.

So far we have been able to think of only one rather crude way to get the energy out of these atomic flywheels. This is to shoot projectiles at them in hopes of breaking them up and causing their fragments to fly off at a tangent, transforming their "angular momentum" into a more accessible form of energy. (We must remember, of course, that this is an extremely rough analogy.)

The methods used differ in detail, but they all work on the same fundamental principle. When two metal plates are charged with electricity of opposite signs and the air is removed from the space between them, an electron, an ion, or other charged particle will move from one plate to the other. The speed with which it moves is roughly proportional to the voltage between the plates. The highest working voltage is now in the neighbourhood of 10,000,000 volts, which gives the charged bodies enough speed to break up some of the

atoms which they encounter at the other end of their run.

Such speed can be imparted by magnetic as well as by electrostatic forces. The effect is the same. A few atoms are broken up. Their electrons and nuclei rearrange themselves into atoms of a lighter element. And some of their internal energy appears as heat, radiation, or electrical tension. This is actually the "transmutation of the element" which the alchemists sought so long and so vainly. But the energy given off as a by-product is considered much more valuable and important than the new elements produced.

Up to the present time this method has not produced any *net energy*. Far from it. The existing apparatus is so crude that the energy consumed is tremendously greater than that given off by the exploding atoms. Still, some energy has been released, a minute amount. It can be measured by the proper instruments. And this small victory has excited, fascinated, even alarmed every scientist who appreciates its implications.

The interest aroused has been so great that thousands of the best minds are working to-day on this one problem. Powerful and costly apparatus has been built and put in operation. Gradually, very gradually, the essential facts are being assembled. As yet we can't see any clear picture. It's rather as if we had a photographic plate with only a few scattered spots developed. But slowly the spaces are filling in. The scientists hope that sooner or later they will get an idea of what the whole picture looks like. When they do, if they do and if their understanding results in control, we shall have to say good-bye to the world with which we are familiar. No line of research has ever promised such revolutionary results.

What are these possibilities of atomic power? We can see them only vaguely, but to use a trite phrase they stagger the imagination. First comes the very interesting

thought that the atomic reaction started by the innocent physicists may prove self-propagating, like spontaneous combustion in a coal pile or the flame of a forest-fire swept across-country by the wind. This is not impossible. Exothermic reactions, those which give off energy, usually continue with increasing velocity until all the available material is exhausted. The glass of the experimental vacuum tube, the walls of the laboratory, the body of the physicist himself, the whole earth, might form equally combustible fuel for an atomic flame.

This is not a possibility which we need worry about. If it happens, it will happen all at once, faster than thought can travel. No one will see it coming or will be able to foresee his own dematerialization for the smallest fraction of a second. The matter contained in the Taj Mahal, Adolf Hitler, and Mahatma Gandhi will contribute in the same instant to the brightness of a new star.

From time to time a " nova ", a new star, appears in the sky and glows brilliantly for a few days, months, or years. No one knows the cause of this phenomenon, although there are theories, most of them based upon the idea of a sudden release of atomic energy. It has occurred to many physicists in their more imaginative moments that the appearance of a nova may mark the end-point of the evolutionary process. That life elaborates until it produces beings sufficiently intelligent to experiment with the mechanics of the atom. Then a new star announces that the final limit has been reached.

The very finality of this possible achievement of higher physics makes it rather uninteresting from the technical point of view. We'll leave it to philosophers and religionists. The other possibilities are almost equally sweeping and somewhat easier to speculate about. Perhaps our physicists will be able to release

atomic energy gradually and keep the reaction under control, as fires are burned in oil-fields. If they succeed in doing this, there will be no part of human life which will not feel the effect.

The first result will be that the economic cost of generating power will disappear almost completely. No more coal will have to be mined. No more rivers will be dammed for power. If the atomic prime movers prove to be small and simple, we may imagine many of them in existence, supplying power where it is used. If not, there will be long transmission lines, as to-day. But these will carry vastly more power, for the conductors may be heated almost to the fusion point. Losses will not matter, for the energy will cost almost nothing.

When atomic power can be generated in vehicles, then we may move through space in some form of rocket ship. Roads and streets, if still used, may be made by fusing the surface of the ground into lava. Whole countries may be heated in winter, cooled in summer, and lighted brightly at night. Transmutation may be developed until any element can be made from any raw material. Platinum from sand, for instance. Or silver from water.

There are many other interesting things which might be done with unlimited amounts of energy at no cost. Everyone may do his own imagining. But I want to warn my readers not to dream of a golden age brought into being by such methods. The net result would certainly be a vast amount of human suffering. The least disastrous effect would be an economic dislocation which would leave most men without function or support. Political disorders would be sure to follow. Tinkering with the climate would probably cause injury rather than benefit. The by-products of transmutation might poison the atmosphere. Powerful radiation leaking out from the atomic power-houses might injure the health

of the human species or destroy its reproductive power. And even if these material disasters did not occur, there are certainly no men on earth who could be trusted to use justly the absolute power over the lives of their fellows which such a technique would give them.

It may be an unscientific thought, but I for one hope sincerely that our physicists do not succeed during my lifetime in tapping the power of the atom. The results would be interesting, but extremely painful.

So much for the sources of energy, past, present, and future. I have spent a good deal of space upon them, for they are important, but the whole situation can be summed up in a single sentence. *There is plenty of power and there always will be.* The development of our civilization need anticipate no resistance from this quarter.

If we run out of petroleum, we can use hydrogenated coal, and there is enough coal for a thousand years at least. We haven't begun to spend our yearly income of water-power. The tides will supply tremendous amounts of energy if other sources become even slightly more expensive. The internal heat of the earth has already been utilized successfully on a small scale. There is plenty more. As last resorts, which we shall probably never use, we have the energy of the sun and the wind, of alcohol and ocean water.

Long before any of these sources, except petroleum, has begun to fail, we shall probably crack the atom and release its superabundant power. The event will mark the end of the present era. Perhaps there will be a conclusive disaster—and a new star for the inhabitants of other solar systems to admire briefly. At any rate, we shall have to adjust ourselves to an entirely different kind of life, based upon unlimited energy everywhere at no cost.

As far as power is concerned, we must look forward to a positive limit, not a negative one. Our energy

sources will not fail, but we may acquire too much energy to handle.

The next chapter will discuss much more immediate problems, the generation of energy and its distribution.

III

THE MUSCLES OF MACHINES

PRIME MOVERS

CRUDE power is no good to us until it is made to do useful work. The energy must reach the proper places, it must be subdivided and distributed to the proper production machines, vehicles, and other mechanical servants of the human race. This chain of events is the central fact of mechanical civilization. Its extent and elaboration are the measures of the progress we have made.

The first link is the discovery of sources of energy: fuels, water-power, etc. The second is the transforming of this energy into mechanical motion by means of various prime movers.

It would be interesting to trace the history of prime movers from the early water-wheels to the mercury turbine, but it would not be very profitable for the purposes of this book. The chief interest of past history is the light it casts upon the future, and prime movers have already approached theoretical perfection much more closely than any other important class of mechanical device. Their future is therefore less interesting to speculate about. They will be modified to some extent; they will be cheapened in terms of the human labour expended upon constructing them. They will increase in size and numbers. But these effects will be secondary, depending upon the development of markets for their power.

Two types of stationary prime mover dominate the situation to-day and will continue to do so in the imme-

diate future, even if we utilize the tides and volcanic power. These are water turbines and the heat engines of various kinds. Both have approached the theoretical limit of efficiency so closely that no very startling improvement is possible.

This is easiest to demonstrate in the case of water turbines. The best of them actually capture 94 per cent of the power of the falling water. There is very little room for improvement here. Some of the remaining 6 per cent will certainly be captured in the future. The cost of the wheels and their installations will be lowered. Better design and better materials will reduce their maintenance cost. But in no case will the advance be startling. There just isn't enough room for improvement between the present efficiency and the theoretical 100 per cent.

In heat engines the situation is rather more complicated, and there is a little room for improvement. Reciprocating steam engines, steam turbines, petrol engines, and Diesels are all heat engines and obey the same fundamental law. Unlike water turbines, they can never approach the point when they get all of the chemical energy out of the fuel they burn. Steam engines have a theoretical top efficiency which depends upon the difference in temperature between the steam which enters the engine and the steam which exhausts into the atmosphere or the condenser. The larger this difference the higher the efficiency can climb. Internal-combustion engines obey the same law, the temperatures considered being those of the gases at the beginning of the power-stroke and in the exhaust.

Naturally, designers of heat engines have concentrated upon increasing this vital temperature difference. But if you heat steam in contact with water, as in a boiler, the pressure increases with the temperature. This fact imposes a practical limit. Metals generally become weaker as the temperature rises. Therefore as the

pressure becomes greater, the boiler parts become less able to resist it. The steam, of course, can be "superheated" after it leaves the boiler, but there is a limit to this also.

At present the highest steam temperature used in the United States is 1,000 degrees Fahrenheit. The highest pressure is 1,800 pounds per square inch at the boiler drum. These have been exceeded slightly in Europe, but the trend is in the other direction. The complications of high temperature are too great and too costly. Power engineers seem to be in fair agreement that the law of diminishing returns is making itself strongly felt here. The increased efficiencies which can be achieved by higher temperatures are too small to make much further development profitable.

In the case of stationary internal-combustion engines, the situation is similar. The initial temperature depends upon the compression of the burning air-and-fuel mixture. In Diesel engines the compression can be increased almost indefinitely, but the difficulties increase in proportion. The walls of the cylinder absorb more of the heat. The piston-head has to be cooled more thoroughly, and the oil injection mechanism gives more trouble. The piston has to travel farther to reduce the pressure and temperature of the exhaust to an economical level.

There is one known way out of this heat-engine *impasse*, but it is not a very promising one. Water yields high temperature steam only at high pressures, but water is not the only liquid which may be used in a boiler. Mercury, for instance, boils at 677 degrees Fahrenheit. It can be heated to 958 degrees before the pressure rises to 125 pounds.

In mercury-steam plants this very hot but low-pressure mercury-vapour runs a turbine and then passes to a water-cooled condenser. Its temperature is still about 500 degrees, so the condenser acts as a boiler and yields

steam at a pressure of 450 pounds per square inch. The steam runs another turbine before it is finally condensed. This gives a total temperature range of nearly 900 degrees without extremely high pressure at any point.

Mercury plants are extremely complicated and expensive, but they are the most efficient heat engines in use at present. Several are in operation, the newest at the Schenectady plant of General Electric.

The practical possibilities of mercury plants, however, are still very doubtful. Mercury vapour is a terrible thing to handle. It can escape through joints which will hold water or steam. It is not only expensive but violently poisonous, and therefore all leakage must be avoided. The cost of the apparatus is very high, to say nothing of the cost of the mercury. And the saving of fuel is at best only a few per cent above the best conventional steam plants.

A recent study has indicated that the most efficient mercury plant would have to operate with a " load factor " of 65 per cent (65 per cent of capacity for twenty-four hours a day) or the fuel economy would not pay for the increased overhead costs. This is an unusually favourable load-factor, for most power plants have one of about 45 per cent or less. It is not likely that mercury plants will ever occupy a very important place in the power situation.

Other " two-fluid cycles " have been considered, and theoretically they show a certain amount of promise. The aluminium bromide-and-steam combination seems to be the most popular at present. Some engineers have even thought of eliminating steam entirely and adopting a liquid which does not absorb so much heat when it boils and which yields a heavy vapour. But these are all very far in the future. At present no such plants have been built, for their cost would more than cancel their advantages.

Some day, of course, we may realize the old dream of turning coal into electricity in a primary battery, but practically no progress has been made in this direction. We may achieve " thermo-couple " power plants. When two metals are welded together and the joint heated, a small current flows through them. This device is widely used to measure temperature, but its efficiency as a power generator is extremely low and has resisted so far all efforts to increase it. Out of the rapid growth of electronics may come some sort of power-generating vacuum tube or related device, but this has not appeared on the horizon yet.

It is always dangerous in this world of rapid change to say that no important improvements are likely to be realized soon, but in this case I feel that I can take the risk. Modern stationary power plants have approached perfection more closely than any other mechanical device. There is still some room for improvement, but the power engineers have done their work so well already that there is a very small chance of any revolutionary prime mover coming into use in the next ten years at least.

In most other technical fields the inventors and designers have only nibbled at the edges, but the power people are far ahead. This is an almost unique situation and requires explanation. The reasons are not hard to find. The energy developed by stationary plants is a single, standard product, especially since electrical transmission came on the scene. The power industry is not hampered by any of the non-technical obstacles which block technical progress in other lines, such as the fashion whims which harass the motor-car industry. The power companies have plenty of money for experimentation, for the public purse can be drawn upon for any amount. Nationalistic tariffs and embargoes have little effect upon power generation. There are plenty of monopolistic practices in the power business, but

they have not worked against technical progress. Each technical economy allows the power magnates a larger margin of profit between their costs and what they dare charge the public. So they have hired the best engineers, paid them well, given them unlimited funds to work with. The net result is a field of technical development which has almost exhausted its possibilities. The fact that the unrivalled efficiency of prime movers has not benefited the public as it should is the fault of financial legerdemain, not of the power engineers.

DISTRIBUTION OF POWER

For a long time in the nineteenth century the development of industrial civilization was hampered by the difficulty of transporting power from place to place. Factories using water-power had to be built close to their dams. When the buildings became too thick around a source of plentiful power, fearful and wonderful networks of ropes, belts and shafts were needed to carry the power a few blocks away from the river. Shafts were not practical above a hundred feet or so. Rope drives consumed all the power in friction at 1 mile. Their practical limit was much less. In various places, New England particularly, the river water itself was led to the factories in flumes and canals. A few of these are still in use in Massachusetts towns, but they worked well only when the " lay of the land " was favourable.

Factories run by steam experienced similar difficulties. Instead of one large, efficient engine, they were often forced to use many small ones, connected by wasteful steam lines. The typical factory before electricity became practical was a madhouse of hot pipes, hissing steam, dangerous shafts and belts.

Electrical transmission changed all that. Both the generator and the motor were invented far back in the nineteenth century. I shall not waste space on their

singularly controversial history. Let it suffice that Edison had nothing to do with either of them, nor with the idea of a central power plant supplying energy to scattered consumers. The idea was obvious and very old. Edison controlled the first practical incandescent lamp and therefore was able to provide a market for the current of the first commercial central station, Pearl Street, New York, 1882. Even this priority claim is disputed. A small hydro-electric station opened near Munich earlier in the same year, as well as another a few months later at Appleton, Wisconsin.

But whoever deserves the credit for practical electric power—and the claimants are legion—the thing itself had a tremendous effect upon all industrial life. Long belts and shaft lines vanished from factories driven by water-power. The engines of steam-driven factories retired into the power-houses where they belonged and sent their energy over wires to motors near the points of consumption. Many small workshops which could not have afforded a steam plant began to use power for the first time. And finally electric power entered peoples' houses, where steam or water-power would never have penetrated.

The first electric stations generated and transmitted *direct* current, as they still do for obscure financial reasons in parts of certain large cities. But direct current had one great disadvantage. There was no convenient way of changing its pressure or " voltage ". In the early days the principal use of electricity was in incandescent lamps. The voltage had to be kept low all along the line, for high-tension electricity is too dangerous to lead through the walls and floors of houses. Therefore Edison's Pearl Street station generated and transmitted its current at 220 volts, twice what we use in our houses to-day.

But low-voltage current cannot be sent long distance over wires of reasonable size without great loss. This

is because of Ohm's law which governs the flow of electricity through conductors. The loss caused by the resistance of the wire has nothing to do with the pressure or voltage. The loss is proportional to the volume or " amperage " of the current flowing. But the *power* delivered at the other end is measured in " watts ", a term which means voltage multiplied by amperage.

So if we want to deliver a certain amount of electric power—say, 1,000 watts or 1,340 horse-power—we can avoid loss by using the highest practical pressure. A one-ampere current at a pressure of a thousand volts delivers exactly the same amount of power as a thousand-ampere current at a pressure of one volt. But the transmission loss shown by the first is one thousand times smaller than the loss for the second. Obviously, then, long transmission lines should carry high-tension electricity, as high as possible.

It was this fact which caused the victory of alternating over direct current. The voltage of alternating current can be changed simply and cheaply by the familiar " transformers ". It can be generated at moderate pressure, " stepped up " to several hundred thousand volts for transmission, and " stepped down " again at the other end of the line. The high-voltage parts of the circuit need carry only a very small volume of current at high pressure. Therefore the losses are small.

This idea was brought to the United States by George Westinghouse, who built an experimental thousand-volt transmission line at Great Barrington, Massachusetts, in 1886. It was 2 miles long, twice as long as the direct-current lines then in existence and much more efficient. The first commercial plant of this type was erected in Buffalo a few months later, and from that date direct current declined, although Edison and his associates placed every conceivable obstacle—political, legal, and financial—in the path of this obvious improvement.

Alternating current plus the transformer is what

makes it possible to send electricity over long distances. Since Westinghouse's original plant, the voltages used have increased year by year, and the maximum length of the lines has increased in almost exact proportion. The longest line contemplated at present will connect Boulder Dam with Los Angeles, 270 miles away. The pressure of the current will be 330,000 volts at the sending end. At such pressure a current not larger in *amperage* than an ordinary house current can carry 10,000 horse-power between the two sets of transformers.

The apparent simplicity of this method—increasing the voltage to increase the practical length of transmission lines—has led a great many people to dream of "super-power" and "giant-power" systems covering the whole country. The idea is to develop the power at the coal mines or the distant water-power sites and send it over thousand-mile lines to wherever it may be required. They propose to minimize the losses by stepping up the pressure to perhaps a million volts.

This is easier said than done. High-pressure current is hard to handle. It makes violent and often successful efforts to escape from the wire. "Flash-overs" between the wires and the supporting towers are as destructive as bolts of lightning. And even if most of the current does stay peacefully on the wire, a part of it always leaks into the air in the form of "brush discharges"—a sort of artificial St. Elmo's fire. These "corona losses", which may be seen as faint halos of light around the wires, become more serious as the voltage increases. They may be avoided partially in various ways, all expensive. But a point arrives when it is no longer profitable to increase the voltage. The cost of avoiding disaster and loss, plus the losses which cannot be avoided, offset the advantages completely.

Even if it were possible to build lines 500 or a thousand miles long, it is extremely doubtful if such lines would

prove economically practical. To the average non-technical observer transmission lines look like a very inexpensive and easy way of moving energy from place to place—much better than shipping coal by rail. But in most cases they are not. The railways are already built. They have many other markets for their services besides carrying coal for power plants. Therefore they can afford to set rates which are lower than the cost of transmission lines which do nothing but carry power.

As a matter of fact, most large power plants can get their coal by extremely inexpensive water transportation. Or they use fuel oil or natural gas, which can be sent very inexpensively through pipelines. Transmission lines at present cannot compete in cost with either of these means of transportation. So the only long lines are those connecting hydro-electric plants with their markets. In these cases there is no alternative.

The familiar transmission lines which criss-cross the country in thickly settled districts are not intended primarily to avoid transporting coal. They are parts of a " network " designed to connect several plants so that they can help one another to carry " peak loads " which occur at different times of the day in different types of community. Or they are intended to enable several cities to get their power from a single large and economical plant which is too big for its home district. If they manage to save transportation charges, so much the better, but that is not their primary purpose.

So at present, with the conventional equipment, the outlook for " giant power " and " super power " is none too good. But there are two possibilities on the horizon which may change the situation. They are still very vague. Little definite has been announced about them. But many able engineers are at work, mostly in the laboratories of large companies. There is at least a fair chance that they will announce striking discoveries when the clouds of the depression finally roll away.

The first and most immediate possibility is a return to direct current for long-distance transmission. The trouble with direct current, as stated above, is that its voltage cannot be changed by transformers. It has to be used at the pressure of the original generator.

This may not always be true. Already the science of electronics has developed thermionic tubes, relatives of radio tubes, which will increase or decrease the voltage of direct current. At present they are expensive, comparatively inefficient, and of small capacity. But much feverish work is being done on them, and most authorities seem to think they have a great future.

High-pressure direct current has various advantages. There is no " inductance loss ", a sort of elastic resistance to the rapid surging of the alternating current. The corona losses, also, are easier to avoid. Direct current does not vary in voltage, as alternating current does. This means that the wire is working at top efficiency all the time.

A direct-current transmission line will consist essentially of gigantic vacuum tubes called " thyratrons " or " phanotrons ". These will take low-pressure alternating current from the generators and " rectify " it into high-voltage direct current. When the line reaches a town, factory, or other consumer, a second set of smaller tubes will tap off some of the direct current and turn it into alternating current of any reasonable voltage or frequency.

An experimental system of this type has been constructed at Schenectady, and it is said to have worked even better than its designers hoped it would. No full-sized line has been built as yet, but to judge from this experiment, the engineers are confident that direct-current lines will carry power from three to five times as far as the alternating-current lines we use at present, and with no greater losses. If this proves to be the case, all the dreams of " super power " will be realized.

We shall still have to use some coal for power generation, but we shall probably burn it near the mines themselves.

The other possibility, transmission of power by radio, is much more distant. Already we can *dispatch* power by radio with fair efficiency. The largest broadcasting stations send out enough current to light all the lamps in a good-sized village. The trouble comes when we try to gather it up again at the other end. Every metallic object catches some of it. Trees get their share. So do lakes, the sea, clouds, and the earth itself. Probably a little penetrates the reflecting layers of the atmosphere and reaches Mars. Not more than a few millionths of one per cent ever gets to its proper goal, the antenna of a receiving set.

There are various possible ways of correcting this inefficiency. Radio waves will follow wires under certain conditions, but when they do so they are nothing but high-frequency alternating currents, very hard to handle in quantity. A better idea is to use the short waves which can be concentrated in beams like light. A bundle of exactly parallel waves would deliver almost all of its power at the other end. But as yet we do not know how to send such beams or how to receive them efficiently. And what would happen to an innocent aeroplane which happened to fly into one of them is an interesting speculation. It might turn instantly into a cloud of smoke and a hail of molten aluminium.

Nevertheless, it would be very dangerous to state dogmatically that radio transmission of power will never be realized. The science of higher physics is in an amazing state of flux and rapid growth. New phenomena are being discovered every week or so. Very sane and competent men are willing to admit, off the record, that they have hopes. Out of the confusion may come some means of transmitting unlimited power over the "air". And if it does, it will certainly affect the whole

pattern of civilization. Ships, aeroplanes, and other moving objects will probably use radio power. Factories will move to new locations. Distant rivers will be harnessed. But all this is still years in the future, if it ever arrives at all.

THE POWER MONOPOLIES

The reader has probably noticed a certain vagueness in the foregoing discussion of power generation and transmission. I realize that I have made few definite statements except that there is plenty of energy available which the world can draw upon when it needs it; that all types of prime movers have become extremely efficient, and that transmission methods have improved rapidly in the last few years and show promise of improving further. So far so good. These are all well-established facts and important ones.

But as soon as I have approached even remotely the questions of power costs, future uses, and future development, I have run into the extraordinary non-technical muddle in which the power industry is floundering to-day. The engineers who design boilers, turbines, generators, and transmission lines have done their work magnificently. This much is certain. But it takes all the ingenuity of a government investigation to find out anything definite about how much these improvements should affect the cost of power.

All industry of course, and all human life for that matter, is entangled in the web of finance. But certainly power is the most pathetic victim of non-technical sabotage by promoters, politicians, and other gentry with ulterior motives. This is not intended to be a book on "social problems", but the matter of energy costs, vital to all modern life, is at least nine-tenths social to one-tenth technical. So now I am going to make a short detour into the boggy field of economics.

The most striking thing about the power business is the amazing spread between the cost of production and the cost to the ultimate user. For steam plants the total cost "at 45 per cent use factor", a fair average figure, is about seven-tenths of a cent per kilowatt-hour. This includes all costs, including an annual fixed charge of 13½ per cent on the total investment. The figures come from power-management sources and are probably somewhat above the possible minima.

But when the power reaches the ultimate consumer who cannot afford to install his own plant, the cost jumps 300, 500, or 1,500 per cent. Some of this increase is legitimate, of course. Even short transmission lines cost money and so do meter readers and billing machines. But most of the increase is ridiculous—based upon inflated capital, high salaries, and dishonest alliances with equipment companies controlled by power magnates for their own financial advantage. In many cities, notably New York, the power companies are in alliance with the gas companies, and the electricity rates are kept up to protect the gas investment, although it has been proved over and over again that low rates will result in increased consumption and larger net revenues. In short, the power companies get away with more murder than any other group except such anti-social organizations as munitions manufacturers and vendors of patent medicines.

The reason for this situation is very simple. The business of supplying power to a given locality is and should be a monoply, like the business of supplying streets and mail service. Duplicate power systems in the same locality would be less efficient and more costly. So the power companies have been given franchises by the local governments. That is, they have been given monopolies on condition that they deliver current at rates which allow only "a fair return on their investment" There is practically no risk involved, for elec-

tricity has no real competition. Therefore the return should be very low, nearly as low as government bonds or the interest paid by savings banks. The books of the companies are in theory open to periodic-public inspection to see that the public is not overcharged.

But invariably, in America and elsewhere, the companies have managed to get control of the government commissions which are supposed to regulate them. Many and curious have been their methods. Sometimes they resort to simple bribery. Sometimes they promise highly paid positions to the commissioners as soon as their terms expire. Sometimes they go in for book-keeping magic which baffles all attempts to clarify it. Sometimes they erect a capital structure so complicated that the progress of a dollar or a kilowatt through its meshes cannot be followed except by those who know the secrets of the maze.

All this is expensive. It requires platoons of lawyers, book-keepers, dummy directors, publicity men. But the companies do not care much, for the cost is added to the public's bill. The prolonged legal-political battles of the public versus the companies are fought with the public's money. The supply is unlimited. The companies never surrender, for the cost of the war is paid without question by the enemy.

I shall not go into the economics of this curious muddle. The details are not easy to understand. One fact alone can prove the whole point. In spite of the notorious inefficiency of government-operated industries, many municipal power plants scattered around the country are able to deliver current at a fraction of the cost in private monopoly localities. This is in spite of many handicaps besides those of political patronage and corruption.

Municipal plants are mostly small and therefore comparatively inefficient. They have not the advantage of being tied into a system covering a whole section of the

country. Most of them are out of reach of water-power which could carry their " base load ". Nevertheless all, practically without exception, do better for the public than their highly efficient private rivals. What's more, they are generally paying off their original debts and soon will be able to provide current at rates which do not include the heavy interest charges. The private companies are supposed to do this also, but their debts invariably increase instead of diminish.

There are plenty of other monopolies and financial conspiracies holding back technical development in practically every field. In fact they are the rule rather than the exception. But the power monopoly stands in a class by itself in the magnitude of its effect upon industrial civilization. Power is to machines what food is to human beings. Modern life to-day, grudgingly supplied with power, is functioning slowly and feebly. Electrical power did not cause the so-called Industrial Revolution, but now that we do use machines and depend upon them, it is a vital necessity of life. As soon as the cost of a kilowatt-hour falls somewhere near its logical level, not much more than one cent, we shall feel a tremendous quickening of all activities in industrial countries.

Recently the chances that this will happen have improved strikingly. The artificial price of power is being attacked on two fronts, the technical and the social. Without indulging in many figures and statistics I shall try to give an outline sketch of this vital battle of the future against the past.

As stated above, the power technologists have done their jobs splendidly. In 1919 the best steam plants used 3·20 pounds of coal for every kilowatt-hour developed. Now they use only 1·51 pounds. This is a reduction of nearly 53 per cent. Steam plants are twice as efficient as they were 15 years ago. The designers of water turbines have done even better. Their most recent

plants capture 94 per cent of the energy of the falling water. Transmission losses have been reduced to a small fraction of the former figures. Equipment of every kind, from transformers to fuses, has improved in efficiency and fallen in cost. Labour charges have fallen also, both the labour used in the generating stations and in maintenance work. In general the power engineers can claim a blue ribbon for services to industrial civilization.

But until recently these improvements benefited very few except the managements of the power companies. Most of the savings went into the pockets of the financial wizards and their lawyers. Large industrial establishments, of course, could erect plants of their own, and many did. But few isolated plants are as economical as a properly linked network. They run only when the factory is in operation and eat up carrying charges the rest of the time, while a network can maintain a good part of its equipment in constant operation. The fact that many large industries found it profitable to install their own plants is an excellent proof that the public utilities were not providing even them with power at proper rates.

Smaller industries had not this recourse. Only very large steam plants are efficient by modern standards. The only factories of average size which could afford until recently to generate their own power were those which required steam as such, for heating or processing. The rest were forced by the inefficiency of small boilers and turbines into the hands of the power companies.

But within the last few years a new factor has entered the situation. This is the Diesel engine, which is now extremely efficient, almost automatic, and low in first cost. It is not as economical as a power network, and will never be, for it has the same disadvantages as isolated steam plants. But modern Diesels have enabled many small power users to generate their own energy

at a cost far below the rates charged by the public *utilities*.

The new possibilities of the Diesel make not only a direct attack on the utility rates, but an indirect one also. At present Diesels are built " by hand ". That is, they are built in comparatively small numbers and so do not justify the use of mass-production methods. They are therefore unnecessarily expensive. But as their numbers increase, their price will fall to a half or a third of what they cost to-day. If the public utilities do not reduce their charges, they will soon be confronted by inexpensive Diesels in every office building and factory using more than a few hundred kilowatts of energy at peak load.

The chances are that the Diesel alone could not break the back of the power monopoly. But within the past year or two many governments, including the American, have waked up to the fact that power is a necessity of industrial life, not a proper source of large private profit. At last they are beginning to realize that cheap power will not merely reduce the monthly bills of domestic consumers. It will speed up all existing industries and found many new ones. It will help the decentralization of industry, a crying need in all industrial countries. Charles Proteus Steinmetz, who tamed the alternating current, said twenty years ago that electricity should be free as the air to all who want it. No government at present goes quite so far as that, but many of them are convinced that power at cost is a public necessity like police protection or the post office.

Among the major countries, England and the United States are doing the most along these lines, but because of local conditions each is going about it in a different way.

England is a small place, most of it thickly settled and highly industrialized. Its power comes from coal, water-power resources being very small. The coal mines are

well distributed, so that no important locality is out of practical transmission distance from the nearest mine.

This set-up makes the problem of power supply a comparatively simple one. The generating stations should be placed in the proper relation to the mines and to the potential users of their power. Then they should be linked up so that the load will be as constant as possible. When the factories of Birmingham are shut down in the evening, the homes of London should take part of the current the factories no longer need.

In the United States this is called a "super-power" system, and many such networks have been built by private companies (without appreciable reduction of rates). But in England the government realized as early as 1919 that no such national utility should fall into the hands of private profit seekers. England is notoriously tender with bondholders, and it is probably lucky for her that she acted when she did, before powerful vested interests could become established.

In 1926 Parliament created the Central Electricity Board and charged it with the task of building a super-power system for the whole country. This is the famous "Grid", which went into full operation in 1935. It cost £27 million for distributing equipment alone besides another £19 million for standardizing the current frequency at 50 cycles a second.

The Grid is a purely distributing enterprise. It gets its power from "selected" stations already in existence or built for the purpose by private capital, but it will not stand for any over-charges. The costs of generating power from coal are well known. When there is no hydro-electric power in the picture, the only opportunity for financial wizardry is in the distribution operations.

The objects of the Grid are to make electricity so cheap that everyone will use it in large quantities. The English in the past have not been large users of electricity. Residential districts were mostly supplied by

local plants at piratical rates. Factories used coal, which was readily available a few miles away. But the Central Electricity Board hopes to change this situation, and has already done so to a considerable extent. There are many " all-electric " homes in Great Britain now, and there will be more soon. Already the English industries manufacturing electric ranges, water heaters, and refrigerators have begun to enjoy an increased market, and electrification of small industry has already improved the industrial efficiency of the nation as a whole.

In the United States the situation does not offer any solution as simple as the Grid. The super-power systems are already built and in the hands of the monopolists. There are the state governments to consider, many of which are owned body and soul by the public utilities. There are vast distances and thinly settled areas, which make a unified system impractical. So the Federal government had to devise another method of attack.

Luckily for the American public, it still controls many of the best water-power sites, and it is these which are being used to break the monopoly. Boulder Dam, Muscle Shoals, and the Grand Coulee and Bonneville projects on the Columbia will, it is hoped, provide such cheap current for their surrounding areas that the American people will demand similar rates from private companies. If Los Angeles gets power from Boulder Dam 270 miles away for a cent or so a kilowatt, the people of Manhattan Island will begin to wonder why the steam station five blocks down the street doesn't give them the same. Its generating costs are only very slightly higher and its transmission costs are practically nil.

I have said that this book is not about " social problems ", and I intend to stick to it. But I have gone into the matter of power costs in some detail because many of the most interesting developments just appearing over the horizon will never reach practical adoption

unless power comes down in price to a natural level. I think that it will, for the reasons mentioned above, Diesel engines and the governmental attack on the monopoly. And in discussing the future of power-using devices I am going to assume that it will.

IV

METALS—THE FLESH AND BONES OF MACHINES

METAL RESOURCES

POWER is the life of our mechanical slaves, the force which makes them move and do our bidding. I have discussed it at length because it is fundamental.

But the slaves themselves are made of metals and alloys. They work with tools of metal. The things they make for us are largely of metal too, with a rapidly diminishing number of exceptions. The world uses vast amounts of metal already, and will use much more in the future.

So before I discuss the machines themselves, I am going to give a great deal of space to the metals of which they are built. In every field of mechanical development the designers are constantly bumping their heads against the limits imposed by the materials they have to work with. When a new steel or light-weight alloy appears on the market, the limit moves upward, and the designers follow joyfully.

Such was the case with railways. The early locomotives crept very uncertainly over their soft wrought-iron rails until cheap Bessemer steel gave them proper rails to run on. Motor-cars were feeble, fragile, disagreeable toys until alloy steels could resist road shocks without too heavy construction. The same was true of aeroplanes. They could never have passed the critical point of peace-time usefulness without the light alloys of aluminium. Entire fabrication methods—die-casting, for

instance—could never have been developed without certain new alloys.

There are two new factors in this field of metals, two new applied sciences with long names and vast possibilities. I am going to discuss both of them, although neither can be described in words of one syllable.

First comes *geophysics*: the scientific method of prospecting for mineral deposits. It is very new, but has already accomplished a great deal. It promises to provide us with ample supplies of every mineral we may require in the future.

Next comes *metallography*: the science of understanding metals and improving them for practical use. It is chiefly responsible for the new alloys so essential to modern industry, and it will undoubtedly accomplish even greater things in the future. It has not begun to exhaust its opportunities.

From time to time articles appear in the press drawing gloomy pictures of what will happen if some essential metal gives out. Sometimes these articles are sincere, but much more often they have commercial motives behind them. A stock-market pool may want to raise the value of certain securities, or a mining company may want to dispose of its surplus metal to speculators. In the summer of 1934 a determined attempt was made to cause the United States Government to buy large stocks of tin for use in case of war. The chief argument was that the "visible reserves" were approaching exhaustion. The government did not buy. It did not need a Senatorial investigation to tell it where the propaganda was coming from.

As a matter of fact, no important metals are becoming appreciably scarcer. Their abundance in relation to their usefulness may be measured roughly by their market price. In some cases this rule does not work. Nickel, for instance, is by no means a rare element.

It forms ·02 per cent of the earth's crust. But its price is kept up by the difficulty of reduction and by the existence of a virtual monopoly which controls the best Canadian deposits and keeps certain important extraction secrets to itself. In general, however, we can estimate the relative scarcity of the common metals by a quick glance at the financial pages of a newspaper. Thus, in rising order of scarcity come iron, lead, zinc, copper, tin, silver, and gold. Any sign that a metal was approaching exhaustion would cause it to shift its position on this list.

Of course it is not possible to estimate accurately the "visible reserves". These figures are the jealously guarded secrets of commercial interests. They are exaggerated or minimized according to the current financial policies of the companies involved. But at least one thing is certain. New deposits of ore are being discovered much faster than they are being mined. The single possible exception is gold, a metal without technical significance.

There are two reasons for this increase of potential reserves. The first is that new mineral regions such as Rhodesia, Katanga, and northern Canada have recently come into the picture. Similar parts will soon be played by the Andes countries, Central Asia, and China. The second reason is more interesting and novel. It is the rapid development of geophysical prospecting, a "tool of to-morrow" with tremendous possibilities.

I am going to spend most of my space upon geophysics and what it may be expected to accomplish, but in passing I want to mention briefly a few reassuring facts about the metallic ore deposits already discovered by old-fashioned methods.

Iron, of course, is the most important metal at present. There is absolutely no possibility of its becoming scarce, even though we use a thousand times as much as we do to-day. Iron is actually one of the commonest

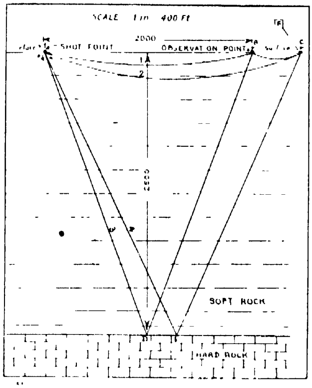
elements in the earth's crust. It makes up about 4·5 per cent of the total. We mine only the very richest ores, and even these are so abundant that they will last for many centuries. If they are ever exhausted and no similar deposits discovered, we can turn to slightly poorer ores which cover large areas in many countries.

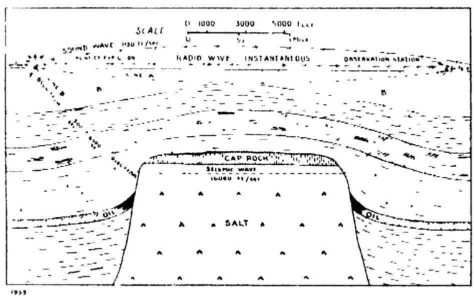
If iron brought the price of copper, we would be able to smelt many of the common rocks, even many of the common soils. In the Carolinas and Virginia, for instance, the red soil is actually iron ore of fair quality, far richer than any of the common ores of copper. So there will always be plenty of iron, even if we do not develop some better metal to take its place. The same is true of aluminium and magnesium, which form respectively 8 per cent and 2·5 per cent of the earth's crust. We could not exhaust them without leaving a hole as large as the North Atlantic.

With other metals the situation is different. In comparison with iron, aluminium, and magnesium they are extremely rare. Copper forms only ·002 per cent of the earth's crust. Lead and zinc less than ·0001 per cent. A new large demand for any of these metals might cause their price to rise and force the exhaustion of the deposits, even the new deposits which would certainly be located by geophysics.

This, however, is extremely unlikely to happen. In the past the metals had well-defined uses. Copper could do things which no other metal could do anywhere near as well. The same was true of lead and tin. This is not the case to-day. The advance of metallography has made the metals largely interchangeable. A small rise in the price of copper would merely give new markets to stainless steel, aluminium, or zinc. The total disappearance of any single metal would cause little difficulty. The metallographers would be quick to design a new alloy to fill the gap. So as soon as the price of a metal

PATHS OF EARTH VIBRATIONS IN REFLECTION METHOD OF SEISMIC EXPLORATION





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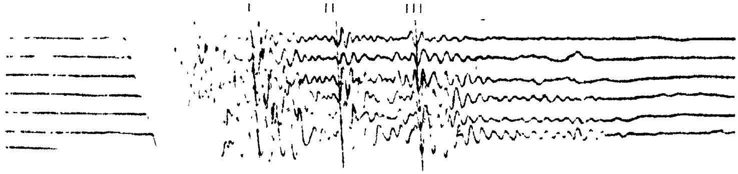

REFLECTION I, II, AND III FROM ABOUT 1,100 FT., 1,800 FT., AND 2,300 FT., RESPECTIVELY, SHOT DISTANCE FROM 550 FT. TO 800 FT. BETWEEN PICK-UPS. CHARGE, $\frac{1}{16}$ LB. OF DYNAMITE

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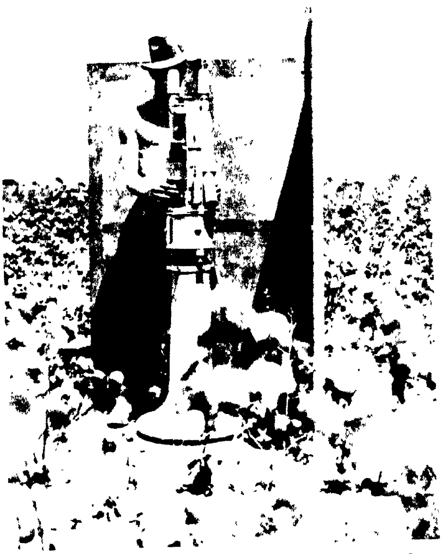
SMALL INCLINED-BEAM
TORSION BALANCE,
SHORT-PERIOD
INSTRUMENT, LATERAL
VIEW, SET UP
IN THE FIELD



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RADIO RECEIVER FOR ELECTRO-
MAGNETIC SURVEY

Photo by courtesy of
The International Geophysics Co.

rises, the demand will fall off and save the deposits from complete exhaustion.

SCIENTIFIC PROSPECTING

Anyone who has travelled in a mineral region will have noticed the old-time prospectors and the signs of their hopeful activity. On the trails and desert roads of Arizona you'll meet picturesque little cavalcades: two or three pack burros led by a shaggy, silent, leathery man. He won't tell you where he's going or where he's been. Often he won't tell you his name. If you give him half a chance, he will try to sell you shares in a silver or copper mine, at one cent a share. The burros will sleep standing up in the sun until the brief, monosyllabic interview is over.

Such prospectors carry little equipment, technical or otherwise. They have a pick, a shovel, a few sticks of dynamite, a hammer and drills, perhaps a gold-pan. The rest of their tools are inside their heads: a vast accumulation of empirical information, experience, hunches, legends, and pure superstition. Yet it was men such as these who discovered practically all of the famous mines in operation to-day.

The old-time prospectors still wander around the hills. Their numbers have probably increased with the unemployment figures. But there is now another type of prospector in the field. He is usually a young man with spectacles and a scientific look. He speaks a technical jargon seldom heard outside the laboratory. He works with amazingly complicated instruments: seismographs, magnetometers, torsion balances—fragile, immensely expensive toys. He moves in "troops" of from five to fifty. And in some way he uses nearly every physical law yet discovered, even those concerning radioactivity and atomic structure.

These are the geophysicists, members of a new and

fascinating profession. Their business is looking into the earth. They can see as far as 20,000 feet down—much deeper than any mine or well is likely to penetrate for many years. Already geophysics has revolutionized the business of finding certain minerals. Its future importance is assured.

Most existing mines are located in broken, mountainous country. There are two reasons for this. Ore bodies are usually found in cracks or "faults" in the rock, into which they have been forced by the pressure of the molten magma beneath the earth's crust. The cracks are made by the same forces that raise the mountains. Therefore the rocks beneath flat lands such as the Mississippi Valley are apt to be uncracked and so devoid of ore.

The second reason is not so fundamental. Mountains are easier to prospect by the old-fashioned methods. Steep slopes of bare rock give useful cross-sections of the strata. Outcrops of ore are easily found, for they are not so likely to be covered with layers of loose material. The old-time prospector, poking up the creek-beds with his borros and pick, had a fair chance of stumbling upon one of them.

But not all flat lands are without minerals. Often their flatness is deceptive. The surface soil may cover the remains of old, worn-down mountains which are just as likely to contain valuable minerals as if they were rough and jagged like the Andes. And unless the soil has been skinned off by glacial action, as in parts of Canada, outcrops in such flat regions are rare. The pick-and-shovel prospector is helpless. He may sink shafts blindly, but his chances of finding anything worthwhile are not very great.

Even in rugged mountains with plenty of bare rock in sight, the surface prospector is still almost blind. Most valuable ores do not occur in large masses which can be followed by geology from their original outcrop.

They are usually " intrusions ", " dykes ", or " lenses " —purely local phenomena impossible to locate unless they happen to come to the surface. When one such deposit has been found, it may pay to search for more like it with a diamond drill. But such drilling costs from two to six dollars a foot and may tell nothing about the rock a yard away from the hole.

Now all this has been changed. The scientific prospectors do not need to see the actual ore. In many cases they can detect its presence under 500 feet of rock. They can estimate its size and get some idea of its composition. They can tell accurately how deep the loose soil is and when bedrock will begin. Often they can predict whether troublesome water is likely to be encountered by the miners.

This has been accomplished by developing instruments which act as new sense organs to supplement our original five. You cannot see a mineral under the earth. You cannot taste it, feel it, smell it, or hear it. An ore body does not send out messages which any of our natural senses can receive. But certain influences do penetrate rock and will bring us information about what lies beneath. These are magnetism, the electric current, electromagnetic waves, gravitational force, and the compressional waves which, when they move through the air, we call sound.

The oldest geophysical instrument is a modification of the ordinary mariner's compass. As everyone knows, a needle of magnetized steel will point to the magnetic north pole in northern Canada, but it also points slightly downward. This is because the " magnetic lines of force " do not follow the curvature of the earth but strike downward at an angle which varies with latitude and local conditions. The " dip " may be measured by hanging the needle on a horizontal pivot instead of a vertical one.

The simplest and oldest use of this instrument, the

Swedish or miner's compass, was to find deposits of magnetic iron ore which act like ordinary magnets and so attract the needle directly. The method was used in Sweden as early as 1640, but did not spread generally to the rest of the world before 1900. It has not proved of great significance, chiefly because magnetic iron ore is very common and occurs in large masses near the surface. A prospector needs no instruments but his eyes to find it.

Finding such ore, however, is not all the magnetometer can do. The " lines of force " can tell it a great deal more about the local structure of the rocks. Every material—rock, ore, or metal—has a quality called " permeability ", which means roughly its power of conducting magnetism. For the ores of iron, cobalt, and nickel the permeability is very high. When a mass of such an ore lies next to ordinary rock, the earth's magnetic force will tend to concentrate in the ore and avoid the rock. Sensitive magnetometers and " earth inductors " can detect such variations even where the differences of permeability are slight.

Compared with the other geophysical methods, magnetic surveys are simple and cheap, but they have serious limitations. The ores of many metals have almost the same permeability as the rocks which surround them. Small amounts of unwanted iron ore may conceal other indications. The earth's magnetism varies hourly and has to be allowed for. On the whole the magnetic method is chiefly useful for tracing the limits of known iron deposits, and studying certain rock-structures. Its greatest recent accomplishment outside this field has been finding a large new reef of gold ore in South Africa. This feat was made possible by peculiar local conditions which are described towards the end of the section.

Another method works by measuring electric currents in the earth. It was developed chiefly in Europe and was first applied commercially in the United States

when Sherwin F. Kelly brought back from France in 1921 the methods and apparatus of Conrad Schlumberger.

Usually the current to be measured must be supplied artificially, but sometimes the ore deposits are thoughtful enough to provide it of their own accord, by what is known as self-polarization.

Some ores consist of sulphides. When such a deposit is exposed to water seeping down through the earth, its upper surface oxidizes slowly and the whole mass acts like a gigantic electric battery. A current passes from the oxidizing part of the ore-body to the unoxidized portion below and returns by way of the surrounding rocks. In doing this it spreads out over a large area on the surface. If the proper collecting devices, called "non-polarizing pots", are touched to the soil, the intensity and direction of the current may be measured with a sensitive potentiometer. It all flows towards one spot, the "negative centre". Directly below lies the ore. Nothing could be simpler. The deposit may be covered by a perfectly level meadow or swamp, but the geophysicist can find it as accurately as if it lay on the surface. This method has proved strikingly successful in Northern Canada and other regions where the ground is wet and where sulphide ores occur.

In many cases this method will not work at all, for the ore sought may not be a sulphide. Then the geophysicist has to supply his own current. One system is to lay out two bare copper wires half a mile long and perhaps half as far apart. They are pegged to the ground every hundred feet with iron stakes and connected with a generator supplying alternating current at 500 cycles a second. The current flows from one wire to the other through the earth.

Generally speaking, rocks and soil are poor conductors of electricity, but some are much better than others. Most metallic ores are comparatively very good. The current will tend to find the path of least resistance

through them, avoiding the poorer conductors on either side. To trace its path the geophysicist connects together two metal stakes by a long flexible wire which passes through a telephone head-set. He drives one firmly into the ground. Then he walks around prodding the earth with the other stake, like a blind man with a cane. If he hears a musical note in the phones, he knows that some of the alternating current is passing through them. When he hears no note, he knows that both of the stakes are on a " line of equal potential ". This means that the current is flowing at right angles to the line between the stakes. After he has plotted a large number of such lines on a map, he knows accurately where the current is flowing. If it tends to concentrate over a certain point, he can be sure of finding an ore deposit or some other good conductor beneath the surface.

This method can be varied by allowing the current to flow between two points instead of two long wires. Or a direct current may be used with a potentiometer instead of a head-set. The principle is the same in all cases. Not only ore can be detected but also wet clay, wet sand, limestone, or any other substance which is a better conductor than its neighbouring materials. There are two chief disadvantages. Water sometimes acts as if it were ore, and in any case the current does not penetrate very deeply.

A higher development of the electrical method, which tells more about the deeper layers, is called " earth resistivity ". It is rather difficult to explain in detail, but the general principle is simple. If two stakes are driven into the earth and connected to a generator, a current will pass between them. The farther apart the stakes the deeper the current will go, spreading out into a half-melon shape below the surface. The resistance offered by the earth and rocks can be measured, and its variation will show whether the current, in its

deep wanderings, has encountered a conductor better or poorer than the rocks near the surface. If the resistance decreases too fast, it means that the deep rocks are better conductors. Recent developments in this method have made it possible to detect quartz veins of the type which may bear gold.

The theories of magnetic and electrical surveys are simple, although the apparatus used has to be extremely sensitive and complicated. But now we come to a geophysical method which will not sound simple no matter how briefly it is outlined. This is the use of an electro-magnetic field, or what we often call " radio waves ".

When a current of electricity flows through a conductor, it establishes around it an electro-magnetic field. This used to be called a " strain in the ether." Now that the ether has been abolished, to the great annoyance of practical physicists, we don't know what to call it. But at any rate it extends to an infinite distance on all sides. When the current changes its direction, the field follows suit. When the current keeps changing continually or " alternates ", the consequent changes in the field are called " electro-magnetic waves ".

Every conductor of electricity which lies in one of these fields is affected by it. When the original current changes direction or " alternates ", a similar but much weaker current flows through the conductor. This is how radio works. The broadcasting station is merely an alternating current in an antenna. The waves move out in a circle like ripples on a pond until they come to the antenna of a receiving set. In this they start weak currents flowing, which may be magnified until they are strong enough to be heard.

Bodies of ore, of course, do not normally act as broadcasting stations. But they can be forced to do so. A long insulated wire is laid out in a loop on the ground and a strong alternating current sent through it. This

sends out powerful waves which penetrate the earth as well as the air. Bodies of ore are usually better conductors than the surrounding rocks. Therefore they will act like the antennæ of receiving sets. An alternating current will surge back and forth within them, keeping time with the current in the wire.

Now here is the trick. Every alternating current sends out waves. The secondary current in the ore body is no exception. It re-radiates some of the power it has picked up. It sends out its own waves, which may be detected by the proper apparatus. Thus the geophysicists make an ore deposit call out its position many hundreds of feet below the surface.

The instruments used to detect these messages from the ore are rather like radio compasses. They consist of " loops ", or special antennæ which are most sensitive to waves coming from a certain direction. Thus they can distinguish between the primary waves from the wire and the secondary waves from other sources. If the rocks are of uniform conductivity, the loop will report nothing of interest. But if a body of ore is present, the signals will tell when the loop is pointing towards it. From the direction and intensity of the signals at various points a great deal may be learned about the size of the body, its conductivity, its position and its shape.

This rough description gives little idea of the delicacy of the apparatus or the intricacy of the calculations necessary. The earth does not send clear messages. The response is likely to sound like a whole orchestra. All sorts of fields are established. All sorts of waves fly this way and that. Some are reflected. Some are bent. Water will broadcast, salt water particularly well. Railways, telephone lines, barbed-wire fences join the chorus and have to be allowed for. But out of the tangle the geophysicists are often able to sift a note which means that an ore body lies at a definite point beneath the surface.

Electro-magnetic surveys have been very popular, particularly in Canada. The apparatus is comparatively cheap and portable, and it will explore a large area quickly. These very advantages, however, have damaged the method's reputation, for it became the favourite of inexperienced men who often misunderstood the indications and reported wet faults or strata as metallic ore.

Another geophysical method measures and interprets the gravitational force of the earth. It started with Sir Isaac Newton, who discovered that "all bodies attract one another with a force which is proportional to their mass and inversely proportional to the square of their distance apart". This law is still in force for practical purposes. The Einstein modification, which has thrown mathematics and higher physics into something very like a panic, is too small to allow its effects to be measured on the earth.

Newton's Law of Gravitation applies equally to all bodies, great and small. The weight of a man is merely the force of attraction between his body and the earth. He is also attracted by the moon and the sun. His two fists attract one another. The Statue of Liberty attracts the Milky Way.

The force of gravitation was first measured by Cavendish, and a modification of his torsion balance is now used by the geophysicists. Cavendish attached two small silver balls to the ends of a light rod and suspended it in the centre by a single silk fibre. Then he placed two large lead spheres on opposite sides of the rod so that each would attract one of the balls and tend to rotate the rod against the resistance of the fibre. By means of ingenious calculations which do not concern us here, he made the amount of this twist yield him the famous "gravitational constant", the force with which two bodies of 1 gram each will attract one another if their centres are 1 centimetre apart.

The Cavendish apparatus is not affected by the earth's

gravitation, for *all* the forces measured are horizontal and therefore at right angles to the earth's pull. Obviously, however, any heavy body would attract the silver ball nearer to it more strongly than the farther one and thus affect the reading of the instrument.

On the other hand it is equally obvious that once we know the " gravitational constant ", we can use the Cavendish balance to measure the mass or the distance of any large body, such as a mountain range or a building, which exerts a gravitational pull not exactly vertical. We might even gather a certain amount of geophysical information with the Cavendish balance, but we do not do so because a similar and much better instrument has been developed.

This is the Eötvös balance, which is designed especially to measure the " horizontal component ", if any, of the earth's gravitation. The two little weights are on the ends of an L-shaped aluminium rod so that one hangs lower than the other. The lower weight is attracted more strongly by any body below the surface. If the body does not lie directly below the instrument, the force of gravity will not be exactly vertical, and the balance will indicate the direction from which the force comes.

Now rocks have various densities. Ores are particularly heavy because of their metal content. Limestone, for instance, weighs 2·3 grams per cubic centimetre, while magnetite weighs 5·2 grams. So if a mass of magnetite is enclosed in limestone, the Eötvös balance will point accurately towards it. If a steep ledge of heavy granite is buried beneath a level covering of light shale, the balance will tell when the granite begins to rise towards the surface.

Modern torsion balances are probably the most delicate instruments in field use. Their sensitivity is amazing. They can detect a force as small as one-million-millionth part of the earth's gravity. They would be able to trace the course of the Holland Tunnel 500 feet below the

surface of the Hudson. They have had to pay for this sensitivity by becoming extremely fragile and tricky. It takes a tremendous amount of skill and care to use one of them in the field.

In practice the first step towards making a torsion balance observation is to select a spot of level ground well away from all roads or railways. A small temporary hut is built to house the instrument. When the preliminary adjustments have been completed, the operator goes away and leaves the rest of the work to an intricate system of clockwork. If he were to return while the balance was in operation, the gravitational force of his body and the vibrations caused by his movements would be apt to ruin the experiment.

Each reading takes nearly an hour, and many are necessary. When the proper time arrives, the clockwork lights a small electric bulb. A ray of light hits a tiny mirror on the suspended rod. Its deflection, registered as a spot on a photographic film, is the reading of the instrument. The clock then changes the film and waits for the next reading. When it is all over, the operator comes back and develops the film. The spots upon it are the starting points for intricate calculations which may reveal structures favourable to an oil field or a sulphur mine.

Sometimes it is desirable to measure not the horizontal component of the earth's gravity, but the actual strength of the pull. This is done with a pendulum, which swings faster when gravity increases. These instruments are at least as tricky as the Eötvös balance and their readings take longer.

In spite of the cost and slowness of the torsion balance and the pendulum, they are used quite widely. They give information beyond the capabilities of any other method. Their practical depth-limit is more than 4,000 feet, which is deeper than the penetration of any instrument except the seismograph, which I shall describe next.

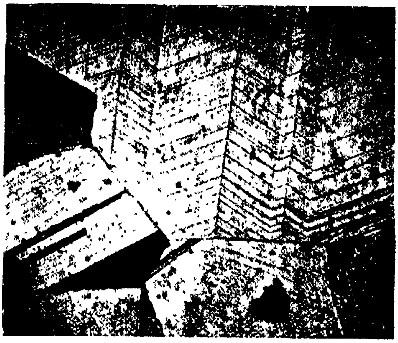
The seismograph is not a new instrument. It was invented many years ago and developed to a high point of perfection for observing earthquakes by means of the shocks which they send through the earth's crust. In theory they are the very soul of simplicity. When an earthquake shock arrives from California or Italy, the ground vibrates a little. If a heavy weight is suspended by a spring, it will remain at rest while the ground moves slightly beneath it. In exactly the same way the body of a motor-car remains comparatively steady while the wheels bump over a rocky road.

The relative motion between the weight and the ground can be measured in various ways, some mechanical, some electrical. The problem is merely to magnify the motion sufficiently and record it on a moving strip of paper or photographic film. Modern seismographs are now so sensitive that the instrument recently set up at Harvard can tell almost as much about a Japanese earthquake as if it were actually in Tokyo.

Earthquake shocks are " compressional waves ". When such waves travel through the air we call them " sound ". Their speed is greater in some rocks than in others. In loose sediments they move 3,900 feet per second. In limestone 12,500 feet. In rock salt 16,000 feet, and in granite 23,000 feet. So by means of the seismograph the geophysicists can " hear " the rocks as they lie many thousands of feet beneath the surface.

First they have to make an artificial earthquake. The natural ones are too infrequent and too complicated. What they do in practice is to bury a charge of dynamite in a hole some 20 feet deep. When it explodes, it sends compressional waves through the rocks exactly as if it were a miniature earthquake. These can be received and recorded by seismographs placed in a ring or a line or a fan several miles from the hole.

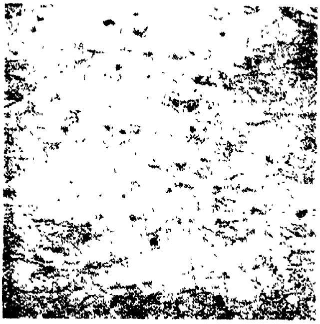
The complete outfit generally consists of a short-wave radio transmitter near the dynamite and a receiving set



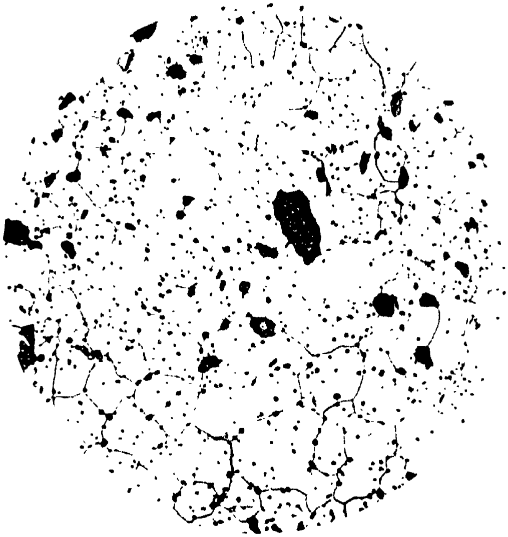
"SLIP BANDS" IN ALPHA BRASS

(after Mathewson)

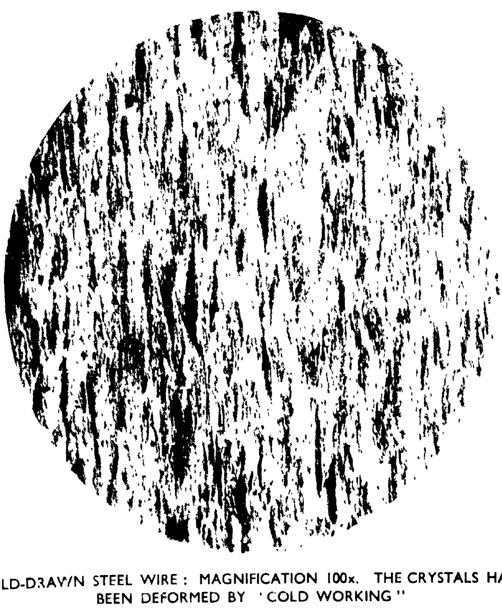
CRYSTAL BOUNDARIES IN ARMCO IRON



From "The Science of Metals", by Jeffries and Archer (McGraw-Hill)



WROUGHT IRON : MAGNIFICATION 100x



COLD-DRAWN STEEL WIRE : MAGNIFICATION 100x. THE CRYSTALS HAVE BEEN DEFORMED BY "COLD WORKING"

Photographs by F. F. Lucas, Bell Telephone Laboratories

on each seismograph. The central operator gives a radio signal and motion picture film starts racing through the mechanism of a " recorder ". Then he presses a key which simultaneously explodes the charge and sends another impulse over the radio. This is recorded automatically on the film, marking the exact instant when the compressional waves started on their way. When they arrive, they are also recorded on the film, and the experiment is over.

Now the waves have travelled by various routes, and so do not arrive at exactly the same instant. Some travel through the loose soil. These are the slowest and so arrive last. Some travel through deeper strata of rock. They have to cover a longer path, but since they move faster, they reach their goal sooner. If another layer of still " faster " rock lies beneath the first layer, there will be another train of waves recorded on the film. The record can be interpreted to tell what kind of rock lies below and how thick the layers are.

This is not all. The waves are also reflected, like sound waves echoing from a building or a cliff. Each boundary between different kinds of rocks gives off reflected waves which come back out of the ground vertically to be recorded by a slightly different type of seismograph. The boundaries are called " horizons " and can be detected as deep as 20,000 feet below the surface. The reflected waves will also tell whether the strata are tilted away from the horizontal.

The seismic method is chiefly used by oil companies, which are particularly interested in the existence and tilt of deeply covered layers, but it will also detect ore bodies if they are large enough and regular enough. It covers a very great area quickly and cheaply.

There are other methods besides those described above, but as yet they have not been perfected. One is to measure the radio-activity of air sucked from the soil. If the reading is abnormally large, it may indicate a

fault in the rock through which radium emanation is escaping to the surface. The rise in temperature of the deeper rocks can be measured and may perhaps yield useful information in the future. Many experimenters have attempted to send continuous sound waves through the rocks, but so far they have not succeeded.

In spite of the proved powers of the successful methods, no competent geophysicist advises blind " wildcatting " with any of them. The earth is too large and too much of its surface covers nothing of economic importance. Geophysics should be used in " likely spots " located by geology, and several of the methods should be used if possible, so that each will check up upon the others.

In the coastal regions of Texas and Louisiana, for instance, most of the petroleum comes from around the edges of " salt domes ". These are rounded masses of rock salt thrust up through the flat sedimentary strata. Sometimes they show on the surface, but much more often they give no visible indication of their presence. Since they may be only a quarter of a mile in diameter, and since they are scattered very thinly, the chances of finding one by blind drilling are very small.

This is an ideal condition for geophysics. Rock salt is low in density, and compressional waves travel through it much faster than in the material which commonly surrounds the domes. Therefore both the gravitational and seismic methods will betray its location. The common practice is to survey a large area with the seismograph; then check up with the pendulum and the torsion balance. If the findings agree, the oil company is pretty sure to find a dome. Whether or not it contains oil is another matter, but the chances are very good. Before geophysics came on the scene the Gulf Coast oil fields were thought to be nearly exhausted. No new domes were being discovered. But by 1933 no less than 110 more were found, most of which contained oil or other valuable minerals.

Another recent example of successful geophysics guided by geology is the new gold reef discovered in South Africa by the magnetometer. The gold of the Rand is contained in parallel veins between layers of barren rock. The " reefs " came to the surface at the point of discovery and have been traced by sinking shafts on either side. There was a limit to this, however. The " overburden " became too thick to make it worth while to trace the wandering ore by such crude methods.

Finally it was noted that the reefs were enclosed in layers of rock which contained iron and therefore had high " permeability ". When a magnetic survey line was run across the probable position of the ore, the curve of the readings showed two sharp peaks a short distance apart, and these proved to be the layers of magnetic rock. Diamond drilling confirmed the discovery. If the ore turns out to be as rich as in the known deposits, which is likely, it is probable that the new reefs will increase the world's production of gold by 25 per cent—which any financier will admit is a major event in economics.

Furthermore, there is an excellent chance that the magnetometer will find the " anticline " where the slanted veins re-enter the earth at a point many miles from the known Rand. If this happens, South Africa's gold production may be doubled or tripled.

Most geophysical work is not so spectacular. The presence of one body of ore proves that the geological conditions are favourable for others near by. Therefore mining companies employ the geophysicists to survey their properties in hopes of finding additional reserves. Very often, in the past, mines have been abandoned while great masses of ore existed near the original workings. Drills and shafts were too expensive to sink extensively.

At the present writing most metals are almost a drug on the market. Gold and silver are the only ones which bring a price which will pay for much develop-

ment work. This condition will not continue for ever, and when the market for metals picks up, geophysics stands ready to find new reserves of ore equal to any demand. It has done so already in some cases, although most of the deposits located have not been developed.

In the future geologists and geophysicists will probably be employed by governments to make surveys of whole countries. When the geologists find an interesting region, the geophysicists will follow them up and search for the specific minerals which are likely to exist under the conditions. It will be very surprising if such work does not reveal great deposits of ore which could not have been found by the primitive prospecting methods of the recent past.

Better supplies of useful minerals will, of course, have a tremendously beneficial effect upon our whole industrial life. Inexpensive chromium and nickel, for instance, would allow us to make most of our steel " stainless ". Common objects of iron or steel would no longer rust, and millions of men would be released from the unproductive labour of painting and replacing them. Inexpensive copper, tin, and zinc would have a somewhat similar effect. Metals such as cobalt, tungsten, and cadmium, now rare and expensive, are sure to prove very valuable in numerous ways once we find their ores in sufficient amounts.

Geophysics has multiplied many times our chances of lowering materially the cost of all these metals. Therefore it occupies a key position in the future development of our civilization.

CREATING NEW METALS

When you take the hide off a steer and make it into shoes, it serves the purpose almost ideally. Nature designed leather for just that job—to resist abrasion while remaining flexible. When you cut down a tree

and use the timber for beams in a house, the same is true. The tubular structure of the wood allows it to resist a maximum of stress with a minimum of weight. That was its job in the tree. Only very recently have we developed anything better for these purposes.

But metals were not designed by nature for anything in particular. Their properties are pure accidents, due to physical laws which have nothing to do with the jobs to which we assign them. They are starting-points, raw building-blocks, while wood and leather are the end-points of a long process of natural selection. Therefore metals are easy to improve. Nature has not been there before us.

From almost the very beginning we have known that alloys may often be stronger than their constituents. We have known that the quality of steel is affected by an amazing number of apparently unrelated factors—such as the temperature of formation, the fuel used, the amount of hammering, the origin of the ore, and the size of the ingot. But until recently we did not know why. Metal-workers followed highly intricate rules-of-thumb, some of which were pure superstition. They could and did improve their product by experimentation, but they understood practically none of the underlying laws. They never knew what would happen if they varied a hair's-breadth from the time-honoured formulas.

Now all this has been changed. The microscope, the X-ray, chemical analysis, and the theories of modern physics have brought a measure of order out of the confusion. A great many important points remain in dispute, but we have learned more about the structure of metals and their alloys in the last twenty years than in all the preceding 4,000. Our knowledge is rapidly bearing fruit in the form of new alloys vastly stronger and better in every way than those discovered by the traditional methods of the past.

The metals used by early civilizations were almost all alloys, natural or artificial. When the primitive metallurgist smelted what he called " copper " from a green or blue stone, he got an alloy of all the reducible metals present in the ore. There might be tin, antimony, arsenic, zinc, lead, iron, or various others. Each ore gave a " different kind of copper ". Some kinds were good for tools, some for ornaments. Some could be cast without blow-holes caused by escaping gas. Some were attractive in colour. Some resisted corrosion especially well.

Gradually rules were formulated. Three parts of green rock mixed with one part of a certain heavy black rock gave a " copper " good for swords. Finally it was learned that the black rock (cassiterite) was the ore of a soft white metal (tin), which could be added to copper and would make it harder and better for swords, although not so good for beating out thin. This alloy came to be called bronze. Certain other stones, although no metal could be extracted from them, made the copper strong and gave it a golden colour. This alloy acquired the name of brass, although the essential metal, zinc, was not isolated until 1509.

Little by little a vast amount of such knowledge accumulated, much of it in the form of jealously guarded secrets. The craftsmen mixed bran into their molten copper. They stirred it with green saplings. They worked only in certain seasons. Why these things were important they did not know, but they were.

When iron arrived on the scene, the mystery deepened. The new metal was exceedingly perverse. If you got your furnace too hot, and fired it too long, the product was apt to be a hard, brittle substance which could not be shaped by hammering. If you added lime, oyster shells, or chalk to the mix, the slag was easier to separate from the metal. But if you got rid of too much of the slag, the iron rusted very quickly.

Every now and then some lucky smith produced a sword with miraculous qualities. It would not bend double in the midst of battle nor lose its edge after a few blows. It would not snap in two or rust away. Such swords were considered gifts of the gods. They often received names—King Arthur's Excalibur was one such. The man who owned one became a hero automatically, for his sword could cut through brass armour, flesh, and bone with gratifying ease.

Such exceptional swords were steel. Gradually men learned how to make them without the assistance of Vulcan, but their methods were dark and mysterious. They smelted the ore just so, with fuel and limestone from just such a place. They hammered the metal for days, buried it in glowing charcoal, smeared it with various strange mixtures, quenched it many times in cold water or oil. The result was steel and often of excellent quality. But no one knew what made it good.

The product of early forges is not to be despised. Only very recently—say thirty years ago—did we learn to make better metal. Damascus and Toledo steel were marvellous triumphs of the empirical method. Some of them contained small quantities of tungsten and other modern alloying ingredients. Japanese swords of the tenth century were made by heating in charcoal and tempering as many as a thousand times. The story that one of them recently cut a Chinese machine gun in half may not be true, but it is not impossible.

Gradually certain underlying rules were developed. Men learned, for instance, that the difference between soft iron, steel, and brittle cast iron was chiefly the amount of carbon the metal had absorbed from the fuel. They discovered that prolonged heating, or annealing, would soften most metals and make them easier to work. Rapid cooling and hammering cold would often harden them. Metals of coarse " grain " were apt to be weak.

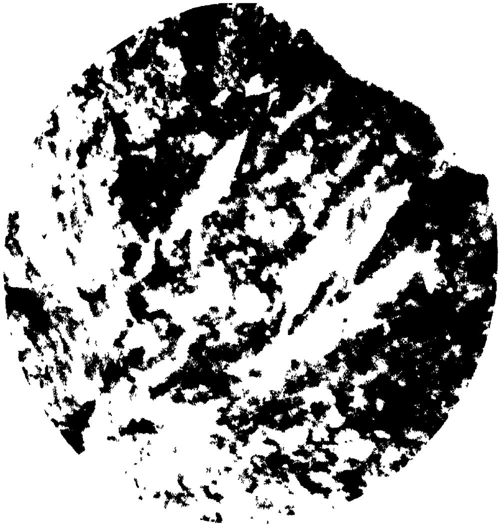
But these rules, too, were purely empirical. No one

knew *why* iron was so greatly affected by minute amounts of carbon. Hammering was thought to "compact" the metal, but this was a very rough expression, for it was known that the metal did not decrease in volume no matter how much you hammered it. The laws governing the tempering of steel remained an impenetrable mystery.

Such was the situation when the science of metallography came on the scene. No definite date can be set for its arrival. Disconnected bits of information had been accumulating at a constantly increasing rate for many years. Some of them were gathered into working rules which covered many cases. Microscopic analysis told a great deal about the coarser structure of metals and alloys, but the microscope was not enough. We could not develop any fundamental theories until the X-ray was turned on metallic surfaces to tell us how the crystals themselves were constructed. This was done in 1911, by Laue, Bragg and Bragg, Hull, and others. If we want a date for the beginning of modern metallography, this is probably the best we can choose.

I shall not try to outline even very briefly the whole of metallography. It is too vastly intricate. There are more than forty metals to be considered, besides non-metallic elements such as sulphur and carbon. These mixed together in varying proportions can yield many billion combinations whose properties depend not only on their chemical make-up but also upon their heat of formation, their rate of cooling, and their "age". We haven't begun to explore the possibilities, but we have already accumulated too much information to be summarized here.

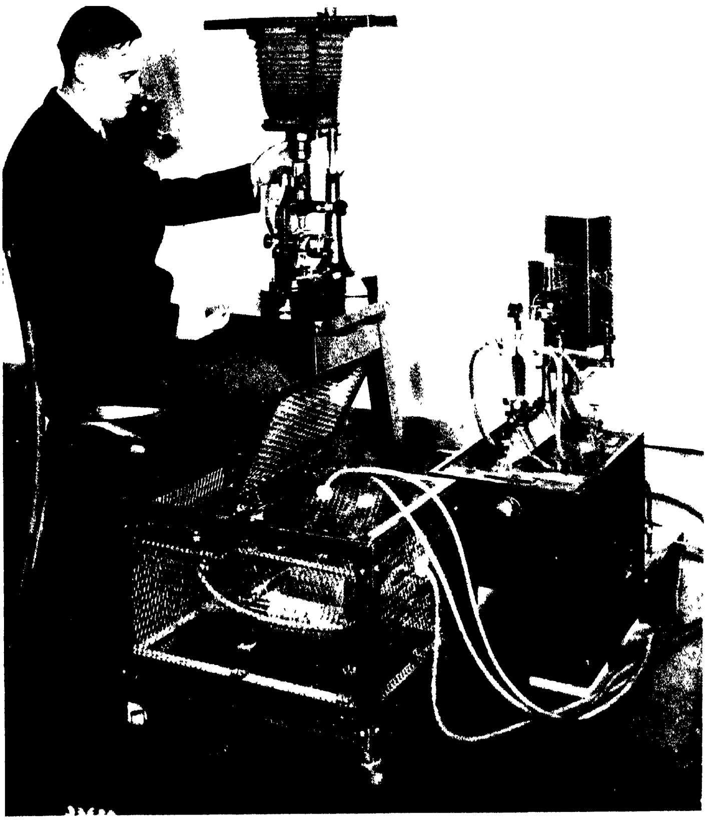
I shall stick to a few general laws which have recently emerged from the confusion. They are more important than all the empirical knowledge of 4,000 years, for they allow us deliberately to design new metals to fill the new requirements of industry.



STEEL, TROOSTITE, MAGNIFICATION 3,500x

PEARLITIC STRUCTURE IN STEEL, MAGNIFICATION 3,300x

Photographs by F. F. Lucas, Bell Telephone Laboratories



By courtesy of F. F. Lucas, Bell Telephone Laboratories

ULTRA-VIOLET MICRO-PHOTOGRAPHIC EQUIPMENT

[*face p.* 103

Metals are peculiar substances. Their usefulness to us depends chiefly upon the fact that many of them are plastic but still have strength and elasticity. This may not seem very remarkable, but it is. Consider how a metal acts when a force is applied to it. With sufficient pressure, copper, a very plastic metal, can be squirted through a hole as if it were water. The " extruded " rod is still plain copper, but it has the strength to resist elastically all forces up to its yield point.

No non-metallic material can act in this way. Pitch, for instance, is plastic, but it behaves like a very thick liquid, yielding to the smallest force if given sufficient time. Clay can be moulded by extrusion, as in certain brick-making machines, but the resulting form has no elastic strength at all. Glass is a " super-cooled liquid ", which cannot be shaped unless it is hot enough to lose its strength. Brittle materials, such as stone, cannot be moulded without destruction.

Metals act as if they were made up of small particles which cling very fast to one another, but which under force can assume new positions relative to one another without letting go. The remarkable part of it is that they cling together just as strongly after distortion as before. Sometimes even more strongly. Other strong materials fracture and crumble. Their particles have no attraction for one another after they have been forced to part company. But the particles of the plastic metals form new bonds as soon as the stress is over.

Until very recently we had no idea why this happened. Metals were so familiar that we took this valuable property for granted, although physicists appreciated the mystery of it. Why should metals yield to certain forces as if they were clay or putty, but resist slightly smaller forces like true elastic solids ? Why didn't they break like rock salt when strained beyond their elastic limit ? We did not know.

The microscope and the X-ray were the weapons

which broke into this citadel of mystery. The knowledge came slow and hard, and the methods used were too elaborate to be described here. I shall confine myself to the final results.

It had been known for a long time that metals were composed of crystals. They are plainly visible on the zinc coating of galvanized iron. Even a small microscope shows them in coarse-grained metal. If a sample is highly polished and then treated lightly with the proper etching solution, the surface shows a network of fine interlacing lines. These are the boundaries of the crystals. Deeper etching shows the crystals themselves, in contrasting tones of light and shade.

If we take an etched sample of a ductile metal like copper and subject it to a force strong enough to distort it permanently, the microscope shows a remarkable change. The crystals have not moved bodily as if they were grains of sand, but across their faces run thousands of fine, exactly parallel lines, which change their direction whenever they come to a crystal boundary. The distortion has taken place entirely *within the crystals themselves*. The boundaries appear to be stronger than the crystalline metal. The deformation of the sample is the sum of millions of minute movements along these "planes of weakness" inside the crystals.

This curious phenomenon remained a mystery until X-ray analysis explained how the crystals themselves were constructed. Visible light can tell us nothing about crystal structure. It is far too coarse. X-rays are electro-magnetic waves related to ordinary light, but their wave-lengths are about 10,000 times shorter. They tell us the essential fact that the crystals are built up of atoms arranged regularly like eggs in a crate.

The atoms do not touch each other in the ordinary sense of the word, but are held in position in space by balanced forces of attraction and repulsion. The space occupied by the crystal can be imagined as being divided

into cells by three sets of parallel planes, each set intersecting the other two like the partitions in an egg-crate. Each cell contains an atom. Though the partitions between them do not actually exist, the atoms do act rather as if they were cubes stacked up like building-blocks.

Obviously such a stack of blocks will not be equally strong in all directions. Tiers of blocks will tend to slide upon the tiers beneath them. Or the whole stack will split along a vertical line. But it will be much more difficult to split the stack diagonally. The corners of the blocks will resist movement in such a direction. Atoms have no corners, of course, but the forces with which they attract and repel each other make them act in a crystal rather as if they had.

All crystals show this tendency to be weaker in certain directions, some more than others. But the crystals of ductile metals have a further remarkable property. When they yield along their " planes of weakness ", the fragments do not fall apart. They merely slide a little. The motion stops and the fragments cling as tightly as before. If the force continues, the motion starts along another plane of weakness. This is what causes the parallel lines or " slip bands " mentioned above. The crystal acts like a row of books standing on edge which " distorts " along the planes of weakness between the books when the end support is removed. The slip bands are the saw-tooth tops of the books after they have fallen over sideways.

The above is a very rough outline of the theory governing slippage in metal crystals. I have left out many fine points and exceptions. Some metals like bismuth and antimony are brittle. Some are brittle at certain temperatures. We don't know exactly what happens when blocks of atoms slide past one another. Some authorities say that amorphous or non-crystalline metal is formed between them. Some disagree. But the funda-

mental theory of the motion along slip planes is generally accepted and has cleared up an extraordinary number of mysteries about the properties of metals and alloys.

It explains, for instance, why fine-grained metals are usually stronger than coarse-grained ones. The slip planes do not cross the boundaries between the crystals, which seem to be more resistant than the crystals themselves. Thus, when the boundaries are close together as in fine-grained metals, the slipping motion is constantly forced to change its direction. This hinders it and makes the metal harder.

Another mystery was why metals grew harder when they were hammered or otherwise deformed by " cold working ". The reason seems to be that the lines where slipping has occurred acquire some of the resistance of the crystal boundaries. This has the same effect as if the metal were of finer grain. If the " cold working " is continued too long, the metal becomes brittle. This means that it is full of the hard boundary material, in which no true slipping can take place. The ductility is restored by " annealing ", or heating to a critical temperature, at which new and larger crystals are formed.

The theory also explains why " solid solution " alloys of two metals can be stronger than either constituent. Solid solutions consist of mixed atoms, like fifty lemons stacked up alternately in a box with fifty oranges. Since the oranges are larger than the lemons, they spoil the smoothness of the slip planes. It takes more force to cause a slip. Alpha brass behaves in this way. It is a true solid solution, consisting of one kind of crystal only. The difference in size of the copper and zinc atoms makes the planes too rough for easy slipping. There is probably another effect as well. Atoms of different elements often attract one another more strongly than atoms of the same element. Thus copper and zinc atoms on opposite sides of a slip plane in Alpha brass cling tightly to each other and so retard the slipping.

Most alloys, including the common steels, are not simple solid solutions, but aggregates, or mixtures of various kinds of crystals, some of which may be pure metals, some solid solutions of two or more metals, some chemical compounds, and some indeterminate substances which have to be given special names. Certain complex steels, for instance, look like rice pudding under the microscope. Certain bronzes look like pressed ferns.

Naturally such complicated structures affect profoundly the properties of the alloys. If one of the constituents is brittle and happens to form a network separating the more plastic crystals, the alloy as a whole is apt to be brittle too. Before plastic slipping can occur, the alloy will fracture, the crack running through the brittle material between the grain boundaries. If the conditions are reversed, with the plastic material in the continuous network, the alloy will be plastic. Slipping can take place in the plastic network without affecting the brittle grains between.

The properties of steel and other iron alloys are largely governed by this principle, but I am not going to use steel as an illustration. Its structure is too vastly complicated. I shall say only enough to show why alloys of nothing but iron and carbon can show so many variations, from soft, nearly pure iron to the glass-hard metal of a knife-blade or a milling-cutter.

Iron has a unique metallurgical history. It is the only metal which forms a large variety of alloys without the intentional addition of any alloying material. The reason is that molten iron absorbs considerable quantities of carbon from the fuel used to reduce or melt it. When the molten iron solidifies and cools, the carbon separates out in an infinite variety of forms ranging from large flakes of graphite (pure carbon) in grey cast iron to fine particles of *cementite*, or iron carbide, which are too small to be seen under the strongest microscope.

This is why ancient steels were often extremely good.

The empirical metallurgists of the past could control the temperatures of their furnaces and the opportunity for carbon to come in contact with the molten iron. They did not know what they were doing, but their operations gave them a large variety of iron-carbon alloys to start with. Their subsequent treatments, " soaking ", " tempering ", and " forging ", were also blind, but enabled them to distribute the carbon in many of its possible arrangements and so to produce excellent steel of certain types.

Iron is a very curious substance. It has several allotropic forms. The most important are Gamma iron, which is stable above 900 degrees Centigrade, and Alpha iron, stable at lower temperatures. The Gamma iron will hold 1·2 per cent of carbon in solid solution, but when it changes to Alpha iron on cooling, this carbon is all rejected except perhaps ·05 per cent. Generally it crystallizes in the form of cementite, a chemical compound of iron and carbon (F_3C) mixed with the crystals of nearly pure Alpha iron, or *ferrite*.

Cementite is the cause of the hardness and strength of most steels and cast irons. Its quantity and its arrangement in the crystalline structure is what makes one kind of iron or steel different from another. When Gamma iron containing carbon in solid solution, technically called *austenite*, is cooled, the cementite is precipitated in a vast variety of forms, depending upon the amount of carbon in the austenite and the rate of cooling. It may appear in large grains, networks, thin layers separated by plates of pure iron (*pearlite*), or microscopic mixtures called *martensite*, *troostite*, or *sorbite*. Several of these forms may exist in the same steel, besides many others of less importance.

Cementite is very hard and brittle. A small amount occupying a " commanding position ", such as a network, makes the steel brittle too. A much greater amount in large, rounded globules leaves the steel

plastic, because there is plenty of opportunity for slipping between the particles of brittle cementite. Pearlite, troostite, and the others also have their characteristic effects according to their position in the structure.

Instead of trying to thread my way through the labyrinth of iron-carbon alloys, I shall explain the principle of slip interference in complex alloys by imagining an abstract metal which behaves very simply. The fact that there is no such metal does not vitiate the illustration.

Let us imagine a plastic metal which takes into solid solution 10 per cent of a very hard brittle substance at a high temperature but throws it out when the temperature falls. Let us further imagine that the hard substance will separate into spherical globules whose size we can control.

Now remember how plastic metals are deformed by motion along the "slip planes" within the crystals. This motion has to change its direction whenever it comes to a crystal boundary, and naturally it has to stop entirely when it comes to a lump of hard material which cannot yield at all. So in a plastic metal containing 10 per cent of hard particles the slipping will be hindered and the metal will be harder than if it were pure.

If the particles are comparatively large, they will have to be spaced rather widely, and therefore they will interfere with few of the slip planes, and the hardening effect will be slight. As the particles become smaller they will have smaller spaces between them. They will interfere with more slip planes and so will make the metal harder. But if they get *too small*, they will no longer act as distinct particles but more like atoms of a different element in the crystals of the metal. The alloy will then be more like a solid solution, harder than the pure metal, but not as hard as if it contained larger particles.

When the particles are just the right size, the hard

substance is said to be " in critical dispersion ". The alloy will have the maximum hardness which can be reached by this method. Many such alloys are still rather plastic, but are astonishingly harder and stronger than the parent metal.

Small particles at or near critical dispersion are called " keys ". If we picture a metallic crystal as a pile of books, the particles will act like marbles imbedded among them. Naturally the books will not be able to slip over one another easily. The more marbles, the more resistance to slip. A few larger particles would act like billiard balls, locking some of the books solidly, but allowing others to slip freely.

Strangely enough, an alloy hardened in this way is often much stronger than the brittle substance which causes the hardness. This is because brittle substances in small particles do not fracture easily. The force acting upon them is distributed among many. They act rather like a sheet of cellophane, which may be torn easily when flat, but which shows great strength if twisted into a cord.

" Keying " the slip planes is certainly the newest and probably the most important of all the methods of improving metals for industrial use. It has not yet been applied to steel, although it is theoretically possible. Steel owes its hardness to particles of cementite much larger than critical dispersion or to the presence of various other elements in solid solution or in compounds analogous to cementite. But aluminium, magnesium, copper, and nickel are hardened in this way, and undoubtedly the method will soon be applied to others. It has been understood only a few years.

Before I describe the recent accomplishments of metallography and its future possibilities, I am going to summarize briefly the principal methods of hardening metals.

1. *Grain refinement.* The smaller the grains the

greater the hardness. The grain boundaries interfere with the motion along the slip planes.

2. *Cold working.* When a metal is hammered or otherwise deformed, the crystals are broken up. This makes them smaller and increases the number of obstructing boundaries.

3. *Solid solution.* The presence of different atoms in the crystals hinders slipping because of the roughening of the slip planes and the greater attraction between unlike atoms.

4. *Slip interference by hard particles.* This effect is felt whenever an alloy consists of two or more kinds of crystal, one of which is harder than the others. It is most marked when the hard substance is in critical dispersion within the crystals themselves.

THE LIGHT METALS

The most interesting metals at present are certainly aluminium and magnesium. Both are comparatively new to engineering. Both are inexhaustibly plentiful. Both are light and therefore suited to modern uses. And they are both peculiarly adapted to improvement by the new methods of metallography. At present they are rather expensive, but for no valid technical reason. Aluminium is produced by a group of corporations which possesses a virtual monopoly and is able therefore to keep the price far above the level which would obtain in a competitive market. The situation in the magnesium industry is similar. The single American producer keeps the price slightly above that of aluminium. Competition from producers in other countries is not effective here because of a duty of forty cents a pound.

The chances are that this condition will not continue very long. Patents will run out. New reduction processes are sure to be developed. The Bohn Aluminium & Brass Company of Detroit has announced its intention

of reducing virgin metal and this threat has already forced the price down slightly. The price of magnesium will have to follow.

These two industries are trembling on the verge of a vast expansion which is sure to affect many other businesses. This will require large amounts of electric power, which will be supplied, probably, by hydro plants in comparatively remote localities. A plentiful supply of these two metals will cause the fundamental redesigning of transportation devices, and if they become inexpensive enough they will enter the building industry to displace many of the structural materials used to-day.

The most striking fact about aluminium and magnesium is their abundance. Aluminium is the third commonest element in the earth's crust. It forms no less than 8 per cent and is exceeded only by oxygen and silicon. Clay contains aluminium. So do most of the commonest rocks. The ore used commercially at present is bauxite, an impure aluminium oxide. This is very plentiful but there is no reason to suppose that it will always be the only ore used. There are too many others which are promising. The Bohn Company plans to use alunite, a basic aluminium potassium sulphate.

Magnesium is not quite so abundant as aluminium, but is certainly abundant enough. It forms 2½ per cent of the earth's crust and is the sixth most plentiful element. Whole mountain ranges consist chiefly of the magnesium-calcium carbonate known as dolomite. Magnesium is found in many mineral waters and in the ocean. The source used commercially at present in the United States is " Michigan brine ", which contains a considerable percentage of magnesium chloride. But if necessary, the metal could be extracted from sea water.

Both aluminium and magnesium are " new " metals. They do not occur in the metallic state in nature, and so they were unknown until comparatively recent times. They were isolated early in the nineteenth century

(aluminium in 1825, by Oersted; magnesium in 1830, by Bussy) but were too expensive to become more than laboratory curiosities. Their reduction required metallic potassium produced by electrolysis, and the only way to generate electricity in those days was by means of batteries, a very costly business. So the light metals had to wait until electricity became available in large quantities at low cost.

By 1886 the time was ripe, and Charles Martin Hall of Oberlin, Ohio, invented the aluminium reduction process which, in modified form, is still used to-day. Alumina, the oxide of aluminium, is almost impossible to fuse and so cannot be reduced directly by passing electricity through it. But it will dissolve in a bath of fused cryolite, a salt which melts at a moderate temperature. When electricity is passed through this solution, pure molten aluminium collects in the crucible.

The reduction of magnesium is a similar process except that no solvent is necessary. Magnesium chloride melts easily and carries the current. Molten magnesium is lighter than the chloride, and so collects on top, where it is protected from the air and its oxidizing effect by a thin film of the salt.

Even when the light metals were finally produced at moderate cost, they were not good for much at first. Both were extremely weak and soft. They could not stand wear, or resist stresses without bending. Aluminium picked up a few minor jobs here and there. It was made into cooking utensils because of its attractive appearance and ability to conduct heat. Magnesium was used chiefly in fireworks and as a catalyst in chemical laboratories. But neither of the metals, in spite of their lightness, could have been successful industrially in the pure state.

Here was a golden opportunity for the new science of metallography. The problem was to increase the strength of the light metals without sacrificing their

lightness. It would have been comparatively easy to achieve strength by alloying them with large quantities of some other metal, as copper is alloyed with tin or zinc. But to do so would have impaired their lightness. The job was not as simple as that.

In 1909 a German metallographer named Alfred Wilm, compounded with true German thoroughness a long series of aluminium alloys. Most of them turned out useless, but one proved to have extraordinary and mysterious properties. When made, it was almost as soft as pure aluminium, but if it were heated to 900 degrees Fahrenheit, then quenched in water and allowed to " age " at room temperature for four days, it quietly gained the strength of mild steel. In those days no one knew why this happened. Wilm's alloy, which he called " duralumin ", contained 4 per cent of copper, 0·5 per cent of magnesium, and 0·5 per cent of manganese. Such small quantities could not affect the strength by forming a solid solution, and the microscope did not show any hard matter like the various forms of cementite in steel.

Duralumin was used for a long time before its peculiarities were understood. Finally the new theories of metallography cleared up the mystery. Copper and aluminium, it appeared, formed a chemical compound, $CuAl_2$, which was extremely hard and brittle. It was soluble in aluminium at high temperatures but was not soluble at room temperature. When the alloy was quenched by being plunged into cold water, the $CuAl_2$ formed a " supersaturated solution ". That is, it tended to separate out, but did not get time to do so while the alloy was cooling rapidly. At room temperature, however, submicroscopic crystals of $CuAl_2$ took shape gradually within the crystals of the pure aluminium. These formed " keys in critical dispersion " if the heating and quenching were properly done, and thus prevented easy motion along the slip planes. The result was an alloy

practically as light as pure aluminium, but as strong as certain types of steel.

Wilm's original duralumin was an empirical discovery, like most of the ancient alloys such as steel and bronze. But it was a very fortunate one, for the subsequent discovery of why duralumin was hard and strong gave the metallographers an extremely useful method which they have been using ever since and which has produced extraordinary results. " Precipitation hardening ", as it is called, has been found to be effective in a great many other alloys.

Modern aluminium alloys, still called duralumin or " dural ", have diverged widely from Wilm's original formula. They no longer depend upon $CuAl_2$ alone as a hardening agent, but also contain small quantities of silicon and magnesium, which combine to form Mg_2Si. The structures of the newest alloys are rather dark secrets, but it is no secret that they are getting better year by year.

Magnesium alloys have a similar history, except that they were developed after duralumin had shown the way. The addition of small amounts of aluminium and other elements improve remarkably the strength of this otherwise weak, soft metal. The newest alloys, called " Dowmetal ", from the Dow Chemical Company, which controls the whole domestic output, compare favourably with duralumin and therefore with certain types of steel.

It is generally agreed among metallographers that we have only scratched the surface of the light-metal possibilities. Not only is it virtually certain that both of them will become less expensive in the immediate future, but it is also unquestionable that their alloys will continue to improve. Aside from their present high cost they have in common one great disadvantage. Their " modulus of elasticity " is low, which means that they are not very stiff, that they cannot resist much force without tending to become permanently distorted. This weak-

ness is counterbalanced by their lightness, which allows greater thicknesses to be used. But the metallographers hope that soon they will improve the " modulus " itself. To judge from the progress they have been making recently, the prospects for such improvement seem very good.

A few figures will show more graphically the contrast between the pure state of the light metals and the effect which alloying and heat treatment have upon them. I shall consider only two properties—" tensile strength " and " Brinell hardness ". The first is the force which a bar 1 inch square will resist before it is pulled apart. The second is an arbitrary scale used to measure hardness.

" Commercially pure " aluminium and magnesium both have tensile strengths of 13,000 pounds. This is very low, lower than the softest copper. Their Brinell hardnesses are 26 and 30 respectively. Very feeble blows will dent them permanently.

The newest alloys present a very different picture. One of the durals (24S of the Aluminium Company of America), when heat-treated, aged, and cold-worked, has a maximum tensile strength of 68,000 pounds and a Brinell hardness of 116. No less than five times as strong and four times as hard. The strongest of the Dowmetals has a maximum tensile strength of 49,000 pounds and a Brinell hardness of 60. It is 3·8 times as strong and twice as hard as magnesium. These alloys are as good in both properties as certain types of iron and steel. Of course they do not approach the hardest and strongest steels, such as those used for knife-blades or crankshafts, but for many purposes such properties are neither necessary nor desirable.

A true conception of the great value of the light alloys cannot be gained from these figures. They do not take into consideration the factor of weight, a matter of extreme importance in the construction of most metal objects. A typical example is metal sheet, which is used

for innumerable purposes from aeroplane wings to cooking utensils.

Sheet steel is stronger and stiffer than either duralumin or dowmetal sheet of equal thickness. It is three times as stiff as duralumin and more than four times as stiff as dowmetal. But it is also heavier. Therefore, sheets of the light alloys can be made much thicker without becoming as heavy as steel. A duralumin sheet of equal weight is 2·80 times as thick as a steel sheet. A dowmetal is 4·44 times as thick.

When we measure the strength and stiffness of such sheets, we come to a remarkable conclusion. Bending strength is proportional not to the thickness of the sheet, but to the *square* of its thickness. Stiffness is proportional to the *cube* of the thickness. Thus a duralumin sheet of equal weight will be nearly *eight* times as strong and *eight* times as stiff as the steel. A dowmetal sheet will be *thirteen* times as strong and *nineteen* times as stiff.

Another way of expressing the same thing is to say that a duralumin sheet weighs only 36 per cent as much as a steel sheet of equal strength. A dowmetal sheet weighs only 28 per cent as much. It is easy to see why these alloys are acquiring dominant positions in certain industrial uses where lightness is important. Where volume of metal is disadvantageous they will not serve, for all the parts have to be made thicker and bulkier, even if lighter than similar parts of steel. But such conditions are comparatively rare. It is weight that usually counts, not thickness.

The light alloys have several other valuable properties besides their lightness. In the first place they are very easily worked. They " machine " readily. They can be cast, extruded, rolled, and forged with the greatest of ease. Since they have low melting-points, they are adapted to " die-casting ", an extremely important process which is coming into use with great rapidity. They resist corrosion well, duralumin better than dowmetal.

Another peculiar advantage comes from the heat treatment. Before the alloys are treated, they are very soft. They can be worked as easily as if they were copper or tin, but after proper treatment they become hard metals capable of resisting far greater forces. An interesting application of this principle is used in aeroplane manufacture. Certain duralumins begin to harden spontaneously after quenching, but rivets made of them will "keep" indefinitely in refrigerators cooled by solid carbon dioxide. When taken out, these rivets are still soft enough to be driven, but forty-five minutes after driving they become as hard and strong as steel.

It is pretty generally agreed that there is a strong trend away from steel and towards the light alloys. How far this trend will go is very hard to estimate. The chief source of uncertainty is that the cost of producing the metals is not publicly known. The price of pure aluminium at the present writing is 20 cents a pound. The price of magnesium per pound is 32 cents. Since both metals are produced by interests which enjoy effective monopolies in their respective fields, there is good reason to believe that the prices are held far above the cost. Several legal cases are in progress at present on this point. To say that the decisions are awaited with interest by the engineering profession would be an extreme under-statement. A decided drop in the price of the light alloys would seriously affect a long list of industries. Steel would lose many of its markets. So would copper and zinc. Even lumber would be affected, for the inexpensive light alloys would certainly be used to replace much wood in furniture, buildings, and truck bodies.

The chief cost item in the reduction of aluminium and magnesium is the electric current consumed. It takes 12·5 kilowatt-hours to reduce one pound of aluminium. The figure for magnesium is somewhat higher. This looks like a lot of current, and it would be if it were

paid for at the retail rates charged to householders. But the light-metal companies do not have to pay such rates. They use, or could use, inexpensive " off-peak " current from hydro-electric plants, available in certain localities at less than half a cent per kilowatt-hour. " Secondary " current from flood water, which would otherwise run to waste, is cheaper still. So it is safe to say that the light-metal companies are not realizing their opportunities if they pay as much as four cents for the electricity needed to reduce a pound of metal.

The only other cost item which amounts to anything is the cost of preparing the aluminium oxide or magnesium chloride for reduction. It is difficult to see why this process should cost more than a few cents per pound of metal. The methods are simple. The reagents are cheap. As for the ores themselves, they cost very little. Bauxite is found in vast quantities in many places and can be " mined " with steam shovels. Magnesium chloride is a by-product from Michigan brine, which yields a long list of other valuable chemicals. If this chloride were not used for magnesium production, it would have to be thrown away.

So much for the light alloys of aluminium and magnesium—the metals of the immediate future. I shall give one more example of how modern metallography supplies us with new materials. The light metals are " alloy bases "—comparatively inexpensive metals used as the principal constituents of alloys. But an equally interesting line of development is the study of expensive rare metals which have profound effects upon other metals even when combined with them in very small quantities.

BERYLLIUM

The metal beryllium has a rather romantic origin. It is made from low-grade emeralds. No serious engineer,

of course, would express it in this way. He would say *that the ore of beryllium* is beryl, a complex beryllium-aluminium silicate with the formula $Be_3Al_2Si_6O_{18}$, whose especially pure crystals of proper colour are sometimes called emeralds or aquamarines.

Beryl, as a matter of fact, is not a particularly rare mineral. It occurs sparsely in most countries. It usually takes the form of large, opaque, hexagonal crystals of various colours, found scattered through igneous rock. It is not thought to be very expensive, but exact information is not available because the only American company which produces beryllium does not like to say exactly what it pays for its raw material.

Up to a few years ago beryllium was a laboratory curiosity and not a very popular one. No one knew very much about it because no one had ever obtained more than a few grams of it in the pure state. This metal has a mad desire to combine with nearly every other element, which makes it difficult to handle. The ore, like most silicates, is extremely troublesome to break down, and it contains only some 4 per cent of beryllium. For a long time, the best the researchers could do was to obtain small quantities of an impure metallic substance which was brittle and hard enough to cut glass.

Finally a process was developed which is similar to the reduction of aluminium or magnesium. Beryllium chloride or beryllium fluoride was fused and reduced by electricity. When the most elaborate precautions were taken to avoid contamination, substantially pure metal was obtained Here was a metal lighter than aluminium but with the rigidity of steel.

This was big news in the metallurgical world, and it produced a considerable sensation. A 250-horse-power aeroplane engine made of beryllium would weigh only about 70 pounds. A motor-car would weigh much less than its passengers. The excitement died down at once, however, when the price was announced. The

first beryllium on the market cost £40 a pound. An aeroplane engine of beryllium might weigh only 70 pounds, but the cost of the metal alone would be £2,800. There were other difficulties as well, such as the discouraging fact that when produced in commercial quantities, beryllium proved too brittle to be rolled into sheets. Evidently it was not destined to be an alloy base, like aluminium and magnesium.

When this was established, the experimenters turned to another possibility. Beryllium has remarkable properties and there was a good chance that small percentages of it would have profound effects on the properties of other metals. So it turned out.

The first metal tried was copper. Metallographers are always trying to harden copper. There are legends that the ancient Egyptians knew how to make copper as hard as steel, but the secret, if it ever existed, has been lost. Brass and bronze are varieties of hardened copper, but they are not very hard—not nearly so hard as steel. And the presence of much alloying material (zinc, tin, silicon, or manganese) reduces greatly one of the most valuable properties of copper, its electrical conductivity.

The first step was to add as much beryllium as the copper would take into solid solution at a high temperature. (A little less than 3 per cent at 1,475 degrees Fahrenheit.) The results were encouraging. The alloy was as hard as good bronze and had excellent conductivity. But the really encouraging discovery was that beryllium is not permanently soluble in copper at ordinary temperatures. If the alloy was cooled rapidly by quenching, the beryllium would remain in supersaturated solution. But if the alloy was cooled slowly, all but a very small amount would crystallize out.

This is a situation which all metallographers watch for alertly, for it is favourable to precipitation hardening, the most fruitful modern method of creating useful new alloys. The problem then became to devise a heat-

treating process which would bring out the beryllium in the form of " keys in critical dispersion ". Much experimentation was necessary, but finally the goal was reached.

The hardening process adopted resembles closely that used for duralumin. The alloy is first heated to 1475 degrees Fahrenheit and quenched suddenly. This leaves the metal about as hard as soft brass (80 Brinell). It can be machined or cold-worked like any fairly soft metal. When the desired form is produced, the finished part is heated for about two hours to a temperature of 525 degrees Fahrenheit. An amazing change takes place. The soft copper comes out as hard and strong as most types of hardened steel. Its Brinell hardness rises to 390, the first time any copper alloy has approached such a figure.

So far no one knows exactly why this happens. It is thought that the tempering precipitates out a new, sub-microscopic phase of beryllium which interferes with " slip " along the crystal planes, but the details are not understood. We only know that the process produces extraordinary results.

Heat-treated beryllium copper is not to be compared with mere mild steel, but to hardened steel. It is somewhat softer than the steel of a knife-blade, but is harder than the steel commonly used in rails and bridges. It is also tough and strong. It conducts electricity much better than any bronze or brass. Its resistance to corrosion is excellent, and it is a good material for strong, low-friction bearings.

Beryllium copper is rather expensive, for beryllium still costs about £5 a pound. But it has already found a large number of uses, and is rapidly finding more. It is especially valuable in small electrical parts, such as brush-holders and snap switches, which have to combine strength with high conductivity. It is very satisfactory when made into springs, valve-seats, and gears. In

general, it is valuable wherever the strength of steel is required, but where steel cannot be used because of its tendency to rust, its low conductivity, its magnetism, or its poor properties for use in bearings.

Beryllium copper has other peculiar virtues besides its strength and hardness. Cold-chisels, hammers, and other tools made of it will not strike sparks if dropped on a concrete floor. This is so important a consideration in industries using inflammable materials that one of the largest tool manufacturers has offered a full line of beryllium copper tools. The alloy is also very attractive in appearance, resembling pure gold. It will probably come into use as a base for gold plate in the jewellery industry.

The manufacturers of beryllium are not particularly optimistic about the future price of their metal. They think it will fall into the " low dollars " per pound, but " never into the cents ". Such being the case, the chances are that it will never take its place commercially among the metals valued primarily for their lightness.

But even if it does not, beryllium is likely to work a minor revolution in the metal world. So far only its copper alloys have been worked out commercially. But beryllium seems to have equally remarkable effects upon the properties of nickel. Beryllium steel is a promising and fascinating prospect. The possibilities of its alloys with other metals have not yet been looked into, even superficially.

I have discussed this somewhat minor matter of beryllium copper in detail because it is an excellent illustration of what metallography can do with a rare alloying element. Beryllium is only one of the list of " future business ". There are many other rare metals and many of them have already been combined into alloys with remarkable and valuable properties.

Tungsten and tantalum, for instance, are fairly familiar and inexpensive. Both of them have been used for

special purposes such as incandescent filaments and special steels. But recently they have been made into a type of alloy which will have an effect upon industry entirely out of proportion to the amount of these metals used.

Both tungsten and tantalum form carbides which are almost as hard as diamonds. Like diamonds, however, they are brittle and without the desirable properties of metals. They cannot be forged, cast, or otherwise shaped into useful forms. They can be used only as abrasives, and for this purpose there are much better and cheaper materials.

A few years ago modern metallography finally solved the problem of how to utilize the hardness of these compounds. By means of a new technique called "powder metallurgy" alloys have been developed which consist essentially of minute particles of tungsten or tantalum carbide set in a matrix of hard, tough metal. These alloys are difficult but not impossible to shape; and when made into tools they can do things which no metal has ever been able to do before. They can cut the hardest steel without losing their edge. They can be run very hot without softening. They have already made it possible for lathes and milling machines to be run several times as fast as before. And the quality of the work is vastly better because the cutting edges retain their original shape for long periods without appreciable wear.

These alloys provide an excellent example of the effect which improved materials have upon invention. Motor-car axles, for instance, can now be made out of steels too hard to shape with other cutting tools. Parts can now be passed automatically from one machine to another without human inspection, for the new hard alloys have largely eliminated a source of possible error in the rapid wearing of cutting edges. Often the mere replacing of tools of old-fashioned steel by tools of

tungsten carbide alloy cuts out a whole series of expensive and labour-consuming operations. The first rough cutting is often as smooth and accurate as the finishing cuts used to be.

With these achievements chalked up to their credit, the metallographers are studying with enthusiasm every rare element they can lay their hands on. All sorts of strange metals are under inspection. Zirconium, for instance, came on the market last year. Research men are busy with it, and perhaps by the time this book is published it will have been put to work.

The list of metals is long, and as yet only the most obvious fields of alloying have been explored. So far perhaps 10,000 alloys have been developed, while many billion are possible. Perhaps someone will discover that 1 per cent of dysprosium, 1·2 per cent of gadolinium, and ·05 per cent of ytterbium will increase some useful property of nickel 1,000 per cent. This is not intended as a suggestion to amateur metallographers, but it is not theoretically ludicrous until proved to be. It would be not much more remarkable than the effect which 2·25 per cent of beryllium has upon copper.

When metallographers look towards the future in their more imaginative moments they ask themselves the question, "How strong can a metal be?" They have not found the answer yet, but they have discovered certain evidence that metals theoretically can be much stronger than any samples we now possess.

When a metal yields to forces acting upon it, the motion occurs along certain definite lines: the "slip planes" between blocks of atoms. The metal can be strengthened by "keying" these planes of weakness or otherwise interfering with their free motions. But no method known to-day can eliminate the slip planes entirely. Weak places always remain.

By theoretical methods it is possible to estimate roughly the strength which metals would have if their atoms

were held together by equal inter-atomic forces. The first step is measuring the attraction between single atoms. This can be done by calculating the amount of energy necessary to separate the atoms by vaporization. The " absolute cohesion " of certain substances explored so far—reduced to common terms—works out to the astonishing figure of 5,000,000 pounds per square inch ! If all the atoms in a rod the size of a fountain pen could be made to pull together, they would support a weight of 500 tons. The best steel cable of that size will to-day support only about 35 tons.

These figures, of course, have very little practical meaning at the present time. No one expects that any of the methods used to-day will produce metal as strong as its absolute cohesion. But at least they encourage the metallographers, for they prove that the science has before it a large supply of worlds to conquer.

V

OUR MECHANICAL SLAVES

THE most important thing which has ever happened to the human race is the appearance of mechanical slaves—the machines which do our work for us. They get their life from the energy-sources described in Chapter II. I think I have proved that these sources are, for all practical purposes, inexhaustible. The bodies of our new slaves are made chiefly of metals and alloys. In Chapter III I have pointed out that we shall never be faced by a metal famine and that furthermore we have recently learned how to develop much more useful metals than those we had before. In neither of these directions is there any obstacle to the development of our new type of civilization.

Now I am going to describe the machines themselves—in particular the principles which lie behind them and the effects which their continued development is likely to have upon our lives. There is no obstacle to be seen in this direction either. We have only begun to explore the possibilities of machines. They have not yet approached their limits of efficiency or usefulness. It is impossible to imagine any material job which they cannot be made to do. Unless non-technical factors force us to change the direction of our progress, it is certain that machines will relieve us of almost all of the work we must do for ourselves to-day.

Machines can be divided roughly into two classes: those which produce useful goods and those which perform desirable services. This classification is not entirely satisfactory. Some machines are hard to place in either

category. Many find a place in both. But the distinction will have to suffice. I shall first consider those machines which produce things useful to human beings directly, or things needed by other machines. Later I shall take up transportation and communication devices, examples of the kinds of machines which perform services.

HOW INVENTORS WORK

In the early days of modern civilization—the seventeenth century and thereafter—a favourite hobby of inventors was the construction of "mechanical men". Beautifully sheathed in polished metal, like knights in armour, they showed off their tricks in the ballrooms of royal palaces. With a loud buzz of clockwork they danced a few steps of the minuet, the inventor following to catch them when they fell. They raised and fired the primitive small-arms of the day. They sat at table, ate tremendous meals, drank gallons of wine.

These creatures never failed to arouse interest, fear, and horror in the minds of those who saw them. Prelates worried about their metallic souls. Generals imagined regiments of them marching with measured steps invulnerably across the battlefields. Philosophers shook their heads and predicted mechanical monsters more intelligent than their creators, without heart or human kindness, cruel, superhumanly strong, lustful and greedy. When Capek wrote his *R.U.R.* a few years ago, he was reverting to the psychology of this period, but he did not fail to get his effect. And he gave us the convenient word "robot", which still produces a small shudder if used with skill.

There was nothing to worry about, however. The seventeenth-century robots were feeble, clumsy things which threatened no sort of competition with ordinary human beings. They could do nothing useful, and therefore they had nothing to offer in return for the effort

of building them and winding them up. Machines have to offer their human masters a bribe of cloth or shoes or ball-bearings before they can obtain from them the gift of life.

If those imaginative men of the seventeenth century who worried about Frankenstein monsters had taken the trouble to go to the less fashionable parts of France, Germany, or the Low Countries, they might have seen something really worth worrying about. In Holland, for instance, they could have found in 1661 a multiple ribbon loom which wove as many as forty or fifty ribbons at once. It was nothing very new. Its inventor had been hanged by the mayor of Danzig in 1529 because his machine threatened to throw men out of work.

The loom, however, did not die on the gallows with its creator. It seemed to possess tenacious, stubborn life. Time and time again it revived—in Leyden, in Lyon, in Germany and Belgium. It could offer a bribe too large to be refused. Fifty ribbons for the labour-cost of one! No hand-weavers' guild could down it for good. Finally, towards the end of the seventeenth century, it was legalized all over Europe. For better or worse it had gained a recognized place in the world.

These two devices, the artificial man-monster and the humble ribbon loom, are examples of the wrong and the right approach to the problem of constructing out mechanical slaves. The monster was a naïve effort to copy the human body directly. It failed because it attempted too much. The human body is vastly intricate. Some of its many billion cells are motors, some are grease cups, some are chemical factories in miniature. The whole assembly is controlled through an electrical telegraph system, the nerves. It is governed by the brain, an appallingly complicated organ which we do not yet pretend to understand. The body of a single human being is certainly as complicated as all the machines in existence in 1935. No wonder the

seventeenth-century monsters could manage only two or three steps of the minuet.

The ribbon loom on the other hand was based on another idea. The inventor noticed that the ribbon-weavers, although their bodies might be as complicated as those of Dante or Leonardo da Vinci, were using only a few simple motions in their work. He judged correctly that a machine could do this stupid task quite as well as a man. He constructed one which an unskilled boy could operate by pulling a couple of levers. It worked well. Then he built five or six more and attached them to the same levers and the same boy. They still worked. The final step was to multiply the original machine by fifty and attach it to a water-wheel. Perhaps before the Mayor's men arrived to take him to the gallows, the inventor may have realized that he had synthesized fifty obedient slaves. But more likely he only rejoiced while he could over stealing a small march on his competitors.

Most of the early machines developed in this way. They merely copied the motions of the human hand going about its productive business with or without the air of hand tools. The spinning-jenny twisted a thread and wound it on a spindle almost exactly as old women had done for several thousand years. The advantage was that a fair-sized water-wheel could keep in motion a thousand artificial grandmothers. The trip-hammer duplicated the motions of the blacksmith at his anvil, but it wielded a heavier hammer and struck more blows per minute than any mortal blacksmith could manage. The wood-working lathe had existed centuries before power machinery was dreamed of. It was a simple matter to hitch it to a water-wheel and make it turn ten times as fast and a hundred times as strongly. The same was true of the potter's wheel, the flour mill, the bellows, and the saw.

All the early inventors did was watch the hand work-

men until they had separated a simple, fundamental routine from its matrix of unnecessary motions. They would construct machines of levers and pivots to duplicate each motion. Then they would put them together, link them up properly, and attach them to the source of power. The final step was either to magnify the machine until it had the strength of many workmen (the power hammer), or to multiply the machine so that it had the effect of many workmen simultaneously busy (the spinning-jenny). Increased speed usually came as a matter of course. And endurance is a fundamental virtue of all machines.

Many of these simple " copy-machines " are still with us, almost unchanged in principle from the day of their invention. They are hard to improve upon, and the chances are that they will be used as long as we need certain products similar to those which were manufactured by hand before the machines came on the scene. An excellent example is the braiding machine which covers flexible electric cords with cotton or rayon sheaths. It works with a smooth, modern hum and moves much too fast to be observed with the eye. But all it does is pass threads over and under one another, exactly like a little girl braiding her pigtail. It does the job better and faster, of course. The little girl has only two hands, while the machine can have as many as it needs. But the braiding operation is the same.

The inventors, however, hadn't been on the job very long before they observed that copying human motions was often not the best way to proceed. Rotary motion, for example, does not exist in nature. There is a good reason for this. All the parts of living animals must be connected by continuous tissues so that they can be " serviced " by the blood and directed by the nerves. Machines are not subject to this limitation. They are serviced and directed by outside agencies and so parts of them can revolve freely if the inventor wants them to.

Rotary motions has many advantages over the reciprocating motion which prevails in nature. A reciprocating part must be started and stopped twice in every cycle. Continual stopping and starting wastes power, makes lubrication difficult, limits speed, and causes vibration. A rotary part spinning indefinitely at constant high speed is easy to lubricate and need not vibrate at all if properly balanced.

So we can see why one of the most important activities of the early inventors was the converting of reciprocating motion into rotary motion wherever possible. It is true that many rotary devices are much older than power machinery: such ancient contrivances as the potter's wheel, the grist mill, the lathe, and the drill, all vastly superior to their reciprocal-motion equivalents. These rotary mechanisms were quickly hitched to the water-wheels of the early machine age.

But in rapid succession other such machines appeared. The reciprocating hand saw became the power-driven circular saw. The carpenter's plane became the rotary planer. The oar became the paddle-wheel and finally the screw propeller. Even homely processes like skimming cream went rotary with the invention of the cream separator.

These two general methods—first, copying the reciprocating motions of hand workers and second, transforming them wherever possible into rotary motions—are responsible for the vast majority of the early machines. Whenever an inventor saw a workman repeating over and over again a few simple operations, he knew that he could build a machine to do better. Whenever he saw reciprocating motion, he at once began to try to turn it into rotary motion. James Watt tried to build a rotary steam engine with a tyre-shaped cylinder long before he had perfected his reciprocating engine. The problem defeated Watt and everyone else for one hundred years, until de Laval's turbine made the steam do its

work by impact instead of by pressure. Many such problems are still unsolved. Literally thousands of inventors have tried to banish pistons from internal combustion engines. The presence of such reciprocating parts in high-speed machines is always a provocative challenge to inventive ingenuity.

The early machines were designed to perform tasks already familiar, such as weaving cloth or smoothing lumber. They met directly existing human wants. But simultaneously they created new wants, and therefore new opportunities for the inventors. For one thing, the machines themselves had to be manufactured. At first this was done by improvised hand methods. The parts were made of wood with carpenter's tools or of metal forged on anvils or cast in sand moulds and finished with files. So few were built that each was a special, individual job.

But as machines became more numerous, repetitious hand motions began to appear in the workshops where they were built. A metal worker hand-finishing a casting with a file is doing no more complicated work than a carpenter planing by hand. Soon the inventors designed milling and grinding machines to do the work of files, metal-lathes to turn shafts and cut threads, power drills to bore many holes while the hand-worker bored one.

These secondary machines would have been practically useless before the primary machines had been invented. Pre-mechanical civilization had little need for shafts, flywheels, or gears. Machines to produce such parts are the reproductive organs of our synthetic slaves. If we had to construct deliberately an entire industrial society with the knowledge we possess to-day, it would be logical to start with the most generalized secondary machines—die cutters or foundry equipment—and let them beget looms, printing presses, and other machines of direct utility. The Soviet Union is doing something of the sort in its effort to build a modern industrial

society upon thirteenth-century foundations. Historically, however, it worked the other way around. We were forced to make by hand many machine-eggs before we could build machine-hens to lay more of them.

I have mentioned so far three inventive methods: first, making machines to copy traditional hand motions; second, improving these machines by building into them rotary and other mechanical movements which do not exist in nature; and third, designing machines to produce machines. This by no means exhausts the list. If it did, the industrial world would not be nearly so full of machinery, as it is to-day.

The people who lived before the age of machines had comparatively few material wants which they hoped even vaguely to satisfy. Human wants above the subsistence level obey the biological law of use. They atrophy or fail to develop at all if they are not stimulated by occasional satisfaction.

But the advent of machines awakened many of these latent wants one by one into clamorous activity. A fundamental human desire, for instance is for mobility, but most pre-machine people were content to walk or ride horseback to market once a week. They would have laughed at the thought of spending an appreciable fraction of their income on mere personal motion from place to place.

But as soon as machines—in this case the railway trains—made inexpensive transportation possible, people jumped at the chance to use them, both for personal transportation and to obtain the products of distant regions. Railways grew and began to demand a vast assortment of new products whose manufacture opened new opportunities for the inventors. The Bessemer converter and the rolling mill are examples of production machines called into being by the railways. The list could be amplified to several pages.

This chain of inventions was lengthened by the motor-

car, which provided still less expensive and still more convenient transportation. Motor-cars hastened rubber on its career and caused the invention of numerous moulding and vulcanizing machines and processes. They provided the first markets for new steels and new alloying ingredients. They called for storage batteries, spark-plugs, starting motors, roller bearings, universal joints, and special gears in vast numbers. Most of these articles were not new, but the motor-car makers were the first to demand them in sufficient numbers to make profitable their production by special machines.

So it was with each new article and service which took the popular fancy. In the days of candles and sperm-oil, people used very little artificial light. It was too expensive, although the latent demand was there. Paraffin increased vastly the demand for light and developed the petroleum industry with all its host of new mechanical complications: machines for the manufacture of drilling equipment, for the production of large pipes, tanks, pumps, barrels, and five-gallon tin cans. The incandescent lamp continued the process. In its trail followed the immense electrical industry with all its innumerable and previously unnecessary production machines: coil winders, automatic wire-drawing devices, glass-blowing machines, and so on.

Other chains of invention were started by steamships, the telegraph and telephone, by wireless, by cheap paper and the impetus it gave to printing and publishing, by modern agricultural implements, by cameras and motion pictures. Each of these industries aroused a latent human want, which grew by what it fed on. And the supplying of each new want opened new fields to the inventors. Not only were they called on to design machines to manufacture telephone instruments, for instance, but they also had to design secondary machines to build these machines. Each new thing which won public support opened a door to a fresh territory for inventors to explore.

Most of these invention-chains cross others at certain points. A machine for producing blades for a steamship turbine will do the same for a powerhouse. Wireless receivers and long-distance telephones use similar vacuum tubes manufactured by similar methods. But always there is something new.

Many doors have recently opened—more, probably, than ever before. Among the most important are aeroplanes, air conditioning, and factory-built houses. At present all these are bearing a heavy burden of hand labour, but as their volume of production increases, invention will replace much of it by special machines. The resulting reduction of cost will increase the volume further, sub-divide hand labour even more, make each operation more simple and repetitious and so allow it to be taken over by machines. This is how industrial civilization grows, and has grown from the beginning. The inventors always have plenty to do.

PRODUCTION MACHINES

In describing the newest production machines, I am not going to try to cover the whole field. There are too many of them. The job would be something like writing a biography for each individual Chinese. I shall concentrate upon certain types which are considered important and which illustrate the general trend.

Nearly all mechanical engineers are agreed that " automaticity " is what the designers are striving for. This, in a way, is a truism. The purpose of all production machines is to replace human labour, and the more automatic they are the more labour they replace.

There is a distinction, however, between automatic machines and machines which act like vastly improved hand tools under the constant guidance of human workmen. A steam shovel, for instance, may do the work of a hundred men, but it is not automatic. Every motion

it makes originates in the mind of the operator. A pneumatic riveting machine is similar. It does much more work than a man with a hammer, but its advantage comes from strength and endurance, not from automaticity. Both of these machines have freed thousands of men from laborious work, but neither operates by itself.

Most machines in use to-day are semi-automatic. They do part of their work undirected, but require human attention the rest of the time. Certain lathes, for instance, will cut intricate parts automatically from a metal cylinder, but they have to be fed with material. A multiple drill-press will bore many holes simultaneously and stop when the job is done. But a human workman must place the next undrilled blank in the proper position.

Most present-day factories consist essentially of groups of such semi-automatic machines. The workmen do not guide them as they guide tools. The human labour is expended upon feeding material and unfinished parts from one machine to another and inspecting them in transit. A few highly skilled men are employed to adjust the machines and keep them in repair.

Fully automatic machines are the next step upward. They do not need to be fed, or started, or stopped. They take their raw materials either from other machines or from large supplies which last for a long time. Once they have been set in motion at the beginning of a working period, they need no further attention unless something goes wrong. The test of whether a machine is fully automatic is whether it consumes any human labour except for adjustment and repair.

There seems to be a popular impression that automatic machines are usually extremely complicated—Rube Goldberg inventions with hundreds of small parts doing unaccountable things faster than the eye can follow. Many automatic machines, on the contrary, are the soul of simplicity. It is, indeed, their very simplicity which

allows them to be automatic. Wire-drawing machines, for instance, will work for hours with no one in sight. All they do is pull coarse wire through a series of dies and wind the product on a reel. They are automatic because it is easy to make them so. Linotypes, on the other hand, are appallingly complicated—baffling mazes of delicate parts with mysterious functions. But they are not in the least automatic. Nothing happens unless the operator presses a key. The reason that they are not automatic is that they do such an intricate job that no one has yet been able to make them work by themselves.

There are two general methods of making machines automatic. The first is to simplify the operation so that automaticity becomes easy to achieve. The second is to take a semi-automatic machine and build into it mechanism which will do the work of the human attendant. The first method is by far the more satisfactory. It is responsible for many simple, cheap machines with vast output. But the second must be used in many cases where the first is impossible.

As an example of the first method I am going to trace the development of metal casting. It is one of the very oldest fabrication processes and one of the most useful. It is fundamentally simple, but it had to pass through a long period of development before human skill and judgment could be eliminated.

The first castings were merely rough bars made by pouring the metal into cavities in clay or wood. Later the moulds were improved so that the metal hardened into some desired shape, such as an axe-head or an ornament.

This simple method was used, practically unchanged in principle, for thousands of years. The moulds were made by packing a damp sand-and-clay mixture tightly around a wooden model or " pattern ". When the pattern was extracted, a cavity was left in the sand which matched its shape. Usually the mould was made in

two parts and fitted together, but often three or more parts had to be used. If the finished article was to be hollow, some sort of core was necessary, which was often made partially of material which would be destroyed by the heat, allowing the loose sand to be shaken out easily. This was called the " green sand " process. It is still used when only a few castings are needed.

A slight improvement was to bake the sand moulds into a sort of weak earthenware. They were more expensive, but were stronger and did not need to be handled as carefully. In both cases, however, the mould was used only once. Each casting required a new mould, whose manufacture required skilled labour.

The first real improvement in casting was the introduction of permanent metal moulds. They were expensive, but could be used many times before they wore out. The metal still had to be poured by hand, and then allowed to cool. The finished casting still had to be taken out, and the mould set up for another pouring. But the metal moulds did not require the labour of men to pack sand around the patterns. Here we see the beginnings of automatic action.

The use of permanent moulds in most cases consumes a much lower grade of skilled labour and less of it. It was comparatively easy to accomplish mechanical pouring. Conveyors were designed which carried a series of moulds under a ladle of molten metal. When they were full they passed on, cooled sufficiently, opened automatically, and returned for another pouring.

But these machines were never very useful. The trouble was the time element. Most metals and alloys, especially cast iron, pass through a pasty stage before they melt into true liquids. Therefore the metal had to be very hot or it would not run into all the cavities of the mould. It took quite a while before it cooled enough to be taken out solid. Therefore the machines either ran very slowly or required a very large number of

moulds. The white-hot metal wore the moulds out quickly. The machines were very elaborate and never became fully automatic.

All these disadvantages could be avoided by using a machine which needed only a single mould. This was accomplished in the " die-casting " machine. Like so many modern methods, it was made possible by the development of special alloys.

Alloys for die-casting must have certain definite properties. They must melt at comparatively low temperatures. They must melt quickly into a freely flowing liquid without passing through a long pasty stage. They must have adequate strength, hardness, and corrosion resistance. Up to a few years ago few such alloys were known, but now the metallographers have developed a great many.

Modern die-casting machines consist of a reservoir of molten metal heated by gas or electricity. The die, or mould, is made of special steel in several parts, so arranged that the casting can be withdrawn when they are separated. The operation is extremely simple. The motion of a wheel presses the parts of the die together. A lever opens a valve and allows compressed air to operate a plunger and force metal under pressure into the die. It solidifies almost instantly, for the alloy is not very hot and all the temperatures are under accurate control. Then the die is opened and the finished casting drops out.

Most of the die-casters in use to-day are semi-automatic. An operator makes three or four motions for each casting. But his work is so simple and repetitious that complete automaticity is easy to accomplish when conditions warrant. Then the machine will go through all the motions without operating attention.

The productivity of these die-casters is astonishing. One of them, about twice as big as a grand piano and costing £1,000, will cast as many as eight pieces a minute.

This is 480 an hour, 11,520 a day, or 4,204,800 in a full year. Such output, of course, would never be reached in practice, but if two die-casters managed to keep in operation only about half the time, they would produce carburettor bowls or radiator caps for the entire motor-car industry of the world.

One operator is required for each of these machines, and his functions are purely supervisory. He checks temperatures, watches the product, keeps the reservoir filled with metal and in general sees that all is going well. Most of the time he has nothing to do and could supervise several machines simultaneously. The cost of his labour, however, is so small compared to the output of the machine, that it is considered good practice to employ at least one man per machine.

Die-casters have already had a tremendous effect upon industry and will have an even greater effect in the future. They are not specialized machines which make one single article, but can produce almost anything, no matter how complicated, if it is made of alloys which they can handle easily. Theoretically, size offers no barrier. The machines can be made as large as necessary. Their size will probably increase rapidly in the future.

This new method, perfected only in the last few years, has worked a revolution in many fields besides that of metal casting. Carburettor bowls, for instance, are intricate things, full of holes of various sizes and bristling with small, projecting tubes, bosses, and flanges. They were formerly manufactured from rough sand-castings by a laborious series of machining operations. Holes had to be bored individually. Sections had to be made separately and screwed into the main shell. But now the die-caster does nearly the whole job. The casting, hot from the die, is almost exactly as required. Very little finishing is necessary.

Such initial perfection saves labour along the line. An

automatic machine to finish the rough castings formerly used for carburettor bowls would have been extremely complicated and expensive. It could have done only this one job, nothing else. Each other article would require another machine equally complicated. But the die-caster, by simplifying the production of such parts in finished form, makes it for ever unnecessary to go to such lengths. Thus it does the work of a thousand special machines.

To-day innumerable familiar articles are made by die-casting, and the list is growing rapidly. They range from small bolts to bodies for vacuum cleaners. The alloys used are mostly based upon zinc, aluminium, or magnesium, but recently brass has been cast by this process. The details are still close secrets. Probably a special brass of low melting point has been developed for the purpose. Steel has not yet been die-cast, but the designers are full of confident hopes. If they can't compound a steel which will melt at a low temperature, they may find some other alloy as hard and strong which will. There are already several on the market which are so advertised. Or they may learn how to make the die-caster out of materials which will withstand the heat of molten steel.

I have described die-casting in detail because I consider it the best recent example of how automatic action is achieved by simplification. The casting of metals is a simple process which will produce complicated things. And simultaneously it makes the castings so exact, so well finished, and so flexible in design that many articles can be cast which were formerly machined, turned, forged, or assembled from numerous parts. So the die-caster is not only an automatic casting machine. It is also an automatic drill-press, lathe and grinder. In fact it can produce very simply numerous complicated shapes which could not be manufactured at all in any other way.

Another example of automatic action through sim-

plification is the extrusion process. Nothing is simpler in theory. Spaghetti has been made by extrusion for at least 2,000 years. The paste is forced through a small hole by pressure to form a long cylinder the size of the hole. Hollow macaroni is made by forcing the paste through a hole which contains a metal pin supported from within the press.

Extrusion of metals is the same in principle, except that metals are harder than flour paste and therefore more difficult to handle. The problem of how to extrude comparatively strong metals has been solved, like so many others, chiefly by the metallographers. They attacked it from both ends. First they found alloys which would soften slightly at moderate temperatures. And second they produced steels for the presses which would stand the tremendous forces necessary.

An extrusion press consists merely of a plunger driven by hydraulic pressure. It fits accurately into a cylinder, at the other end of which is a hole of proper shape. An ingot of metal is heated moderately and placed in the cylinder. The plunger moves forward, forcing the metal through the hole. The action can be made wholly automatic if desirable.

Nothing could be simpler. But extrusion can produce a long list of complicated shapes which formerly had to be made by a series of rolling or drawing operations, or which could not be made at all. It will make tubes, I-bars, T-bars. It will make bars with cross-sections like Fs or Zs. It will make bars with curved cross-sections and bars containing longitudinal holes. In fact it will make almost any shape of uniform cross-section, large or small.

Like the die-casters, these extrusion presses replace a large number of non-automatic or semi-automatic machines. Simple structural shapes, such as I-bars, could be rolled, although no rolling machines are nearly so automatic. But more complicated shapes had to be

welded or riveted together from several simpler strips. This could seldom be done except by laborious, non-automatic methods.

Extrusion has been a boon to various industries, notably aviation. Certain light alloys of aluminium and magnesium lend themselves easily to the process, and modern aeroplanes use many extruded shapes, especially in the wing structure. The designer works out the ideal cross-section for each member, and the press makes it exactly to order. Copper and certain copper alloys are also extruded, principally into tubes. Tin and lead are extruded very easily. Tooth-paste tubes are made by a modified press which strikes the whole tube, threaded neck, shoulders and all at one blow from a tin slug—44 blows a minute—6,000,000 tubes a working year. One operator watches several machines.

Another beautifully simple machine method is called " broaching ". It is very new. Perfected broaching machines have been on the market only a few years, but already they have affected the large-output industries profoundly. All mechanical engineers are agreed that they will develop into a mass-production tool of primary importance.

Broaching machines are almost laughably simple. They are nothing but glorified files. The " broach " is a long steel bar carrying thirty teeth, more or less. They are made of the best and hardest metal, and their cutting edges are ground with extreme accuracy. Mechanical engineers are indignant to hear them called files, but that is what they are, nevertheless.

The simplest broaches are used to form flat surfaces upon metal objects. The part to be surfaced is held firmly in a fixture designed for the purpose, which moves forward automatically into position. Then the broach descends slowly. The first tooth cuts off a thin chip. The second tooth extends forward slightly more and so takes off another chip. The third another, and so on.

The last few teeth are "finishers". They are ground with extra accuracy, and are set so that they do not remove solid metal, but merely smooth off irregularities left by the "roughing teeth" which have preceded them. When the first finishing tooth has been worn down slightly, the second will do its job for it. The broach does not have to be reground until all the teeth have lost their accurate edges.

The broach passes only once over the face of the unfinished part and makes no other motion whatever. The cutting speed is comparatively slow, and therefore the teeth do not become very hot. There are no small parts to get out of order. No adjustments are necessary except to grind the broach and place it in position. It lasts an unusually long time between grindings.

Broaching machines will also form surfaces which are not flat. In fact, the teeth may be shaped to cut and finish any surface which is curved in one direction only. This includes the concave, semi-cylindrical bearings which are so numerous in motor-cars and other machines. Several broaches may be used simultaneously to do two or more separate jobs without complicating the machine or consuming more labour. They can be mounted on sprocket chains, or the work can move instead of the broach.

At present most broaching machines require an operator to feed them with unfinished parts. As in the case of die-casters, their output is so great—up to 1,000 pieces per hour—that the cost of this labour is insignificant. But they are so simple that it is easy to combine them into chains of automatic self-feeding machines. This has already been done in a few cases and will certainly be done much more often in the future. It is the complicated machines which are difficult to make wholly automatic, not the simple ones.

I have discussed die-casting, extrusion, and broaching as examples of ultra-modern machine methods which

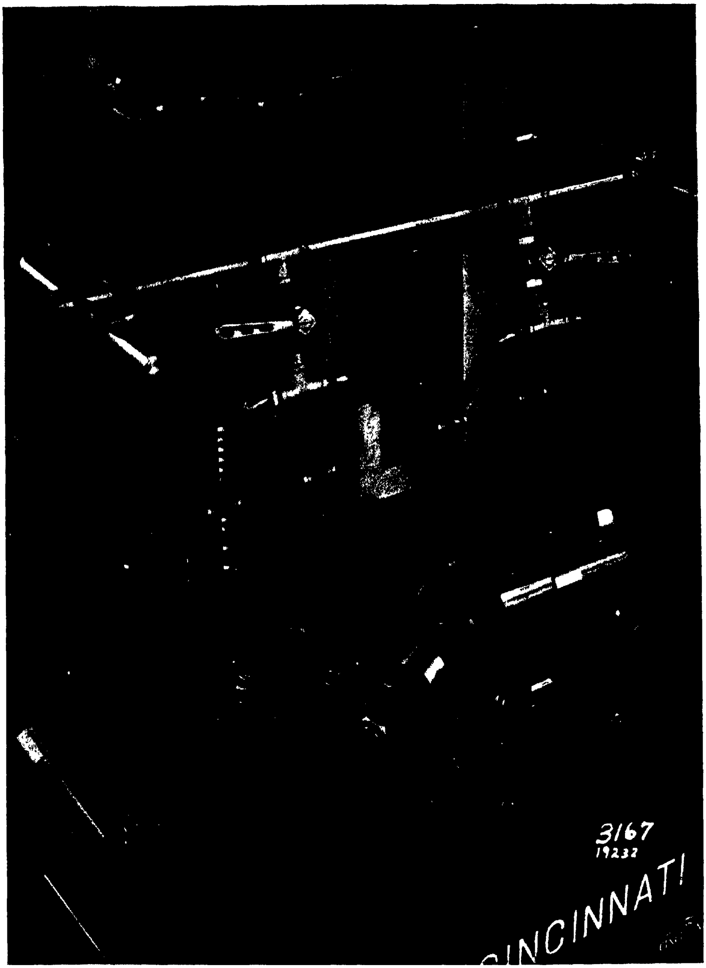
accomplish vast amounts of work almost automatically because they are fundamentally simple. The list could be longer. Automatic forging machines are developing rapidly. Welding—melting two pieces of metal together where they touch—is replacing many intricate threading and riveting operations. And so on.

But many jobs remain which have to be performed by comparatively slow methods which have been in use for many years, such as boring and turning on a lathe. These processes have been speeded up considerably by the use of improved alloys in the cutting tools, but there is a limit to this. In many industries certain slow machines are still necessary, and much human labour is consumed in feeding each one with rough parts.

When a machine cannot be speeded up by simplifying its action, the designers resort to another method. They try to link the machines together in a continuous chain so that one feeds the next. This makes them all more automatic, for it eliminates the human operators who formerly stood between them.

There are several ways to do this. The most obvious is to equip each machine with an automatic feeding and ejecting mechanism. When the first machine gets through with a part, it places it on some sort of conveyor and sends it to the next machine, which seizes it and sets to work on the next operation. This is always possible, but is something of a makeshift. Such a chain occupies a great deal of space and is hard to keep co-ordinated. The ejecting, feeding, and controlling mechanisms are expensive and likely to get out of order.

Much better results are achieved if all the machines in the chain can be compacted into a single unit which performs all the desired operations on many parts simultaneously, passing them around internally from one cutting tool to another. Such super-machines have been used in rather primitive form for many years, but they have recently become much more versatile and effective.



By courtesy of the Cincinnati Milling Machine Co.

BROACHING MACHINE AT WORK ON CONNECTING-ROD CAPS

[face p 146]

By courtesy of the Bullard Co.

A "MULT-AU-MATIC" MILLING MACHINE AT WORK ON AIRPLANE-ENGINE CYLINDER HEADS

[face p. 147

No single name covers all of them, but the trade names they are known by usually contain the root " multi ", as in " Mult-Au-Matic ", the type which I shall describe as an illustration.

This type consists essentially of six or more revolving spindles which hold the work. They are arranged in a circle around a central support. The operator clamps a rough part to the spindle which is at the loading station. Then the " indexing ring " moves and takes the part to the first working station. The spindle revolves and a cutting tool moves down from overhead or one side and cuts a shaving from one surface of the part—from the outer rim of a flywheel, for instance. While this job is in progress, the operator is placing another rough part on another spindle at the loading station. When this job is done, the first part moves to the second working station. Another tool performs another operation upon it while the first tool is repeating its work on the second part and the operator is loading the third spindle.

This process continues until all of the working stations are busy. When the first spindle gets around again to the loading station, the part which it carries has been worked upon by five or more different tools. Since all these are busy simultaneously the total time is only the time which would have been consumed in the finishing of one part if performed in a separate machine. And only one operator is required.

These " Mult-Au-Matics " will do all sorts of things besides the simple turning operations described above. They are not merely machines, but a manufacturing method which can be adapted to a wide variety of tasks. Each working station can carry almost any type of tool moving or fixed, or several of each. They can bore an almost unlimited number of holes in a part by means of multiple drills. They can " generate " spherical surfaces, or any other regular shape for that matter. In fact each working station is an independent machine

which does not require manual feed or other attention. There is no theoretical limit to their size or the number which can be built into one "Mult-Au-Matic." Broaching machines can be made " Mult-Au-Matic ". The underlying principle can be extended to cover nearly any type of machine where work requirements call for a series of cutting operations on the same piece.

Multiple machines can be designed in many other ways to fit a particular job. Sometimes the unfinished part is clamped into a holder which is pushed from one machine to another on a slide, stopping automatically when it reaches the proper spot. Every time it stops, a new tool advances to do its work. Two or more of such lines can converge, allowing several parts to be combined at the junction point. The parts can be heated, wound with wire, painted, or treated with chemical solutions. As long as they are always held mechanically, no human labour is consumed in feeding any of the linked machines.

This attempt to make machines serve one another is by no means new. It dates almost from the beginning of mechanical civilization. But quite recently it has come into greater prominence. There are several reasons for this besides the general principle that larger factories can use high-output machines more efficiently.

When machines are linked together, it is necessary to control them accurately. If one machine runs faster than it should, it will upset the operation of the whole chain. Some units must run fast, some slow, but all must keep in step. They can be connected by a rigid system of gearing, but this destroys the flexibility of the chain. If the article produced must be modified slightly for some reason, a great many expensive changes are necessary before each machine is adjusted to the new conditions.

Recently developed " power drives " have made it much easier to control machine speeds with flexibility

and accuracy. Some of them are electrical—motors which are efficient over a wide variety of speeds. Some are hydraulic. These consist of pumps which supply oil under pressure to oil-motors connected with the machine. The volume and pressure of the oil can be controlled very easily. This governs the speed of the machine, having the effect of a " transmission " with an infinite number of speeds.

The other modern development favouring multiple machines is the tungsten carbide cutting alloy described in an earlier chapter. When each operation is performed in a separate machine under the care of a workman, he has plenty of opportunity to watch the cutting tools. As soon as one of them gets out of shape, he can stop the machine and replace the tool without interfering with any other machine in the shop. But when many machines are linked together, there may be fifty tools cutting at once. The man in charge of the super-machine cannot watch them all carefully. And what is even more serious, he can't adjust or change a single tool without throwing the entire series of machines out of operation. As the number of tools increases, the idle time of the whole chain tends to increase in proportion. There comes a point when they are " out " so much that they are no longer economical.

This limit to the number of automatic machines which can be linked together efficiently moves upwards with each improvement in the metals of which the cutting tools are made. It took a tremendous jump with the development of tungsten and tantalum carbide alloys. These are so amazingly hard and wear-resistant that they last many times longer than " high-speed " steel. Now a whole chain of machines can often run several days before a tool has to be replaced or adjusted.

Machines using tungsten carbide cutters are more expensive to build. The alloy is rather brittle and therefore the least vibration or " chatter " may break the tool.

Total elimination of vibration requires heavier construction and sometimes entirely different design. But the advantages of the new cutting materials are so great that many plants are now scrapping their old machines. They are sure to do so even more frequently in the immediate future.

There is one more recent development in machine methods which I want to mention. It is not particularly important at present, but it puts in the hands of the machine designers an entirely new weapon—new in *kind*, not merely in degree.

Until a few years ago machines were blind things. They responded chiefly to touch. They stopped when a sensitive part came in contact with some solid object placed there for the purpose. Their parts moved when some other part, by touching them, gave them the signal. A few machines possessed electrical senses unknown to man. But none of them had *sight*, the sense which man finds most useful. There were no machines which would not operate equally well in total darkness. They had no eyes to miss the presence of light.

Photo-electric cells are the artificial eyes which promise to equip our mechanical servants with sight. They are usually vacuum tubes containing a cathode in the form of a plate covered with a substance which gives off electrons when exposed to light. These electrons can be gathered up into an electric current which is proportional, within limits, to the amount of light falling upon the cathode. There are other types of photo-electric cell, but they all do the same thing. They measure the strength of light. This is exactly what our eyes do. The only difference is that our eyes contain many millions of cells.

The commonest job for the artificial eye at present is to note the approach of objects which may not be touched safely or conveniently. It will count motor-cars crossing a bridge, for instance. A strong beam of light shines on the cell from across the roadway. When a passing

car interrupts the beam, the current from the cell drops suddenly. This works a relay which magnifies the effect, and the passage of the car is recorded by some sort of mechanical counter.

There are many other objects which should not or cannot be touched by a blind mechanical finger. The cells will open a swinging door when a waitress in a restaurant interrupts a ray of light in front of it. They will count freshly painted articles on a conveyor. They will sound an alarm when black smoke rises from a factory chimney.

But they will do a great many more interesting things as well. Certain textile machines, for instance, work best when a loop of fabric hangs down between them. Its length is important. Two cells, each with its beam of light, are so arranged that when the loop is the proper length it keeps one in shadow, but not the other. If the loop gets too short the dark cell is illuminated. It gives a signal and an appropriate mechanism lengthens the loop. If the loop gets too long, it casts a shadow on both cells. The mechanism responds and shortens the loop.

The cells will also sort various objects according to surface appearance—something no blind machine will do. Tin cans of food, for instance, are labelled automatically as they roll down conveyor channels. Sometimes one of them fails to pick up its label. Usually a human employee watches the stream of cans and picks out the offending ones, but a photo-electric cell can do the job quite as well at much less expense. A strong beam of light plays upon each can in turn. When a shiny, bare can comes along, more light is reflected into the cell. It responds instantly. A mechanical hand reaches out and pushes the can off the conveyor.

If objects are to be judged according to colour, the cell watches through a coloured window. Red apples, for instance, look black through green glass. Therefore,

no light reflected from them will reach the cell. But when a green apple passes by, a flash of green light tells the cell to knock that particular apple into the discard.

Another interesting application is in safety devices to protect the operators of dangerous machines. A typical set-up consists of a beam of light reflected back and forth by mirrors to form an intangible barrier between the operator and the point of danger. As long as the operator's hand interrupts any part of the reflected beam, the cell will not allow the machine to work.

Printing presses use the cells in still another way. No blind machine can tell whether or how a sheet of paper has been printed. Certainly not when the paper is racing through the press at aeroplane speed. But a cell will watch for printed spots upon it, and if they do not come at exactly the right interval, it will either correct the error or stop the press. This is very important in certain types of multi-colour printing, where the successive impressions must " register " perfectly.

I could continue to give such examples for several pages, but none of them would be very important. Photo-electric cells have not yet come into their own in industry. They are too new and too unfamiliar to appeal to hard-boiled shop foremen, who suspect their mysterious ways. But imaginative engineers insist that they have a great future. Indeed, it does not take much imagination to think of innumerable jobs they may be given to do.

At present almost all human workmen use their eyes. Often they are employed to watch for a small list of possible irregularities in the operation of a machine or a process. They look for holes in the finished product. They see that moving objects do not pile up on conveyors. They watch the level of materials in bins and reservoirs. Such jobs can often be done much better and at less cost by artificial eyes. It is certain that some of them will be done this way in the future.

Eventually we shall probably develop complex cells which can " see " shapes as well as mere light and shade. These will be able to judge moving objects accurately for size and regularity. They will tell whether paint has been applied properly, whether plated objects have been polished all over, whether heat-treated castings have warped out of shape.

With the knowledge which we possess at present, such " eyes " would become fantastically bulky and expensive long before they approached the human eye in ability to detect forms and colour gradations. But already photo-electric cells are both quicker and more accurate than the eye in measuring variations in the intensity of a single beam of light. They can watch continuously without rest. They can transform the information they gather instantaneously into any kind of mechanical motion. They are sensitive to heat rays and ultra-violet rays which do not affect the human eye. They will undoubtedly improve in many ways, but even as they are to-day they are candidates for many jobs now performed by human eyesight.

Machines are no longer blind.

ORGANIZING OUR MACHINES

A few years ago the press was full of " technocracy ". All sorts of rather naïve persons excited themselves and frightened the public by calculating the potential output of various new machines. The figures they evolved were impressive. One plant employing about two hundred men, it seemed, was able to make all the motor-car frames in the world. One road machine could parade around the country laying concrete pavement faster than a man could walk. And so on down the list. The final result of the technocrats' calculations was to the effect that our existing mechanical slaves would produce everything we needed with only two hours of

work a day from every able-bodied man—*if they were properly organized.*

But they were not properly organized then, and they are not yet. They won't be for a long time, if ever. Conditions are too unstable to allow even the existing machines to settle down to industrious peace. The frame plant mentioned above has never worked more than a fraction of the time. Smaller, more flexible plants compete with it successfully although they are not nearly so well equipped. Roads are still built by methods which allow for local conditions. Civilization is not as simple as the technocrats thought it was.

So I am not going into an orgy of theoretical production figures. They mean too little. Before we can benefit fully from the abilities of our new servants, we must solve the economic, social, and political problems which bother the world at present. We must do something about nationalism. We must see that labour unions do not force the retention of obsolete equipment to " make work ". We must see that financiers do not do the same thing to " protect investments ". We must devise means of distributing the output of our factories to the people that can use it. We must learn to divide human leisure more evenly so that the population will not consist of unemployed with too much of it and employed with too little.

These difficulties are not technical ones, but they must be overcome before our machines can work unhampered. Some of them are yielding now. Some are growing worse, notably nationalism with its trade barriers and threats of war. But solving these problems is not what I mean by organizing machines.

The " political " organization of our mechanical servants to-day may be compared to that of the Mongolian tribes before the birth of Genghis Khan. They were warlike and numerous, and the ruggedest kind of individualism was the rule of the day. The Mongols were

so completely busy stealing cattle and killing one another that they had no energy left over for efforts outside their natural borders.

What Genghis Khan did was to turn the energies of Central Asia in one direction. He stopped intertribal warfare, decreed that the cattle should graze in peace, made travel safe and communication sure. His consolidation of these intertribal squabbles resulted in a redirection of energy which allowed the Mongols to conquer most of the known world. This was an unqualified disaster, of course, for the Mongols as well as for their neighbours. But a similar redirection of machine energy could do as much good as the Mongols did evil.

At present many of our mechanical slaves, like the early Mongols, are occupied in fighting one another. One type of this intertribal warfare starts with the development of a machine or a method which cuts to a fraction the cost of making some useful article. All the established manufacturers who can afford it buy the machine, increasing their potential output many times. To pay for their investment they all calculate that they will have to capture larger proportions of the available market. Therefore they advertise widely and expensively. They increase their sales forces, allow larger commissions, resort to all the tricks known to commercialism. The price of the product may fall to some extent, but most of the advantages of the new method have been cancelled by the cost of the selling and the enforced idleness of the over-numerous machines. In many cases to-day the retail price of an article produced chiefly by automatic machines is three or four times the cost of production. Often the small manufacturer who could not afford to buy the new equipment finds himself as well off as the large one who has the machines but cannot keep them profitably busy.

One effect of this is to slow down the introduction of the newest and most efficient equipment. The manu-

facturers look ahead, see trouble approaching, and so do not invest their money in machines which would certainly cut their legitimate production costs, but might not yield tangible profits.

There are other types of intertribal war among high-output machines. One of the most harmful from the point of view of the buying public is the deliberate manufacture of low-quality goods which wear out quickly and have to be replaced sooner than necessary. This is caused by the commercial desire to " make a market " for the output of surplus machines, and it is much more common than is generally realized. It causes tremendous waste of material, labour, and machine efficiency. Often the same machines could produce long-wearing goods at almost the same cost if adjusted differently or fed with slightly better material.

Another phase of this effort to force unnecessary replacements is the familiar propaganda to convince the public that last year's models are obsolete. Typewriters and sewing-machines, for instance have not improved, appreciably for the last ten years, and it is practically impossible to wear them out in ordinary service. But new models appear every year, usually dressed up with new gadgets of small utility. A considerable part of the public is persuaded to scrap its old machines for new ones which are hardly better.

This may be good business for the manufacturers, but it is bad business for society as a whole. It results in much unnecessary effort and waste. The old models are wasted directly when scrapped. And the machines which made them often have to be scrapped as well.

When " obsolescence " does not suffice to stimulate profitable replacement, some industries resort to " styling ". Their sales departments try to convince the public that superficial appearance is an all-important factor. This results in such absurdities as " streamlined " refrigerators and " modernistic " gas-ranges. In

some industries, particularly women's clothes, the rapid fashion changes agreed upon annually by the manufacturers have prevented almost completely the adoption of efficient machine methods. Automatic dressmaking machines are wholly practical in theory. They would reduce the cost of the product immensely. But no manufacturer wants to buy expensive equipment which he knows may be rendered obsolete within a year by a change of fashion. So the clothing industry still uses much hand labour and comparatively inefficient general-purpose machinery, which can be shifted over easily from one style of product to another.

Mechanical engineers in general are not especially emotional men, but they tear their hair when they observe the condition outlined above. There are practically no industries which could not be improved immensely in efficiency by adopting machines already designed. Some of these industries are kept near the handwork stage by fashion changes. Some, already well mechanized, are working only a small part of the time because their "selling cost" keeps the price up and the market small. Some are split into such small units by financial jealousies that no individual manufacturer has enough money to equip his plant properly.

But in their optimistic moments the engineers like to forget these things and turn their minds to what *might* be done if we had a Genghis Khan to make our machines work efficiently together. They are convinced that human beings still work much too hard for what they get. Machines are ready to do almost all the work of the world, but before they can operate efficiently, we must arrange them in mass-production units.

POSSIBILITIES OF MASS PRODUCTION

"Mass production" is a rather misleading phrase and I have avoided using it until I could qualify it

sufficiently. It is not always true that a large plant can produce a given article more cheaply than a small plant, even when they both pay the same prices for materials and labour. Mere size does not save labour unless it makes possible the adoption of additional automatic, large-capacity machines. When all the machines in a small plant are already automatic there is no advantage in doubling the size of the plant. It will merely mean that twice as many men produce twice as much output. There may be savings in " administration " and " selling " costs, but these are not technical factors.

In the textile industry, for instance, large size is not considered very advantageous. In a modern cotton mill the operation of spinning thread or weaving cloth is almost completely automatic. The workers merely watch the machines, adjust them, keep them in order. When all goes well, most of them have nothing to do. This does not mean that they are often idle, but they deal with exceptional events, such as the breaking of threads. Such duties are not repetitious and so cannot be delegated to machines.

A short row of looms watched by a single operative is in itself a mass-production unit. Half a dozen such units plus the secondary machines, foremen, expert mechanics, shipping staff, etc., can make certain types of cloth as economically as if the factory were a hundred times as large. Which is why there are so many small, thriving cotton mills still in operation.

But this is a condition not very common in modern industry. Most products are not so simple as cloth, nor are they made by as short a series of operations. In industries producing complicated products, mass-production methods have only begun to take effect. The typical factory of to-day is a combination of automatic machinery, semi-automatic machinery, and hand labour. The choice of machines depends very largely upon the amount of the product the management hopes to sell.

Let us suppose, for instance, that the intended output of a plant is 100,000 complete units a year. Certain highly developed automatic machines work at or near this rate. They will be used. But others work at a vastly greater rate. They would be advantageous if they could be kept busy, but if they are sure to be idle most of the time, the management will prefer to have their potential jobs done by semi-hand methods. Certain operations are extremely simple. One man can perform several of them by hand upon the entire output of the plant. His job will be secure for the moment, for it would take several expensive machines in intermittent operation to replace his labour.

But if the management decides to multiply the capacity of the plant by ten, the situation changes. Many high-output specialized machines will be installed because the higher rate of production will keep them busy a large part of the time. The men who tended the semi-automatic machines formerly used will lose their jobs, and the cost of their labour will be saved. A certain amount of hand labour will still be required—to fill odd chinks and crannies between the machines, to clean up chips to carry small parts from place to place. But more of the employees will be of that higher type of labour which supervises machines but does not help them at their work.

Each increase in output continues this process. But the amount of labour saved by successive increases tends to lessen. In the plant we have just been considering, there were certain machines which worked continuously and automatically to make 100,000 units a year. Ten of each will be required for an output ten times as large. There is no labour saving here. A second increase of output—say, to ten million units a year—will similarly remove the advantages of many of the automatic machines installed after the first increase. Finally, a point will be reached when practically everything is done automatic-

ally, as in textile mills. The machines can be improved in various ways—made to work faster, more uniformly. They can be constructed so that they get out of order less frequently and require less adjustment. But no mere increase of size will save much labour.

This point, however, has been reached in very few industries. The overwhelming majority of them still employ men at monotonous, repetitious tasks which could be delegated to machines if the volume of output were large enough. Even in the newest motor-car factories we find such men.

Consider, for instance, the broaching machine described in a previous chapter. A man stands on the platform and feeds unfinished parts into the claws of the machine. His motions are highly mechanical and repetitious, so much so that it would be easy to replace him by an automatic feeding device. Almost any mechanical engineer would undertake the assignment with perfect confidence of success.

But the output of the machine is so huge—over a million pieces in a normal year of 8-hour days—that few factories need more than one or two of a kind. It would save very little to build the equipment to feed them automatically. There may be other broaching machines in operation nearby, but they handle different parts and so would require different feeding mechanism. If the output of the broaching machines were one-tenth as large, many more of a kind would be required, and the operators would have been forced off their platforms long ago. The very efficiency of the machines keeps them only semi-automatic.

This is the condition in a great many industries. Almost all of them still employ hand labour. And the primary reason is that their output is not sufficient to justify more automatic machines. If all the motor-cars in the world were made in a single plant, much less labour would be required. Many operations now per-

formed by hand would acquire sufficient volume to justify automatic machines. Ten or more self-feeding broaches would be watched by one man. Other semi-automatic machines would become automatic. And most of the "inspectors" would be replaced by automatic weighing, measuring, and testing devices, which at last would find enough work to justify their installation.

So the first thing the mechanical engineers would do if they had their own way would be to see that the volume of each factory was increased to the limit. They would have all the cheap cars made by one firm, all the middle-priced by another, and all the high-priced by a third. The effect upon production cost, they are sure, would be amazing. If the selling costs were also to be eliminated by some non-technical reform, we could probably buy present-day motor-cars for something like a hundred dollars apiece. (Engineers are not concerned with the financial profiteering in which such monopolies would certainly indulge.)

Competition between manufacturing companies is not the only factor which keeps production figures down and therefore prevents the full adoption of automatic machinery. Nationalism, with its tariffs and embargoes, is guilty too. Each industry is now being encouraged to set up in each country plants which are too small to use many automatic machines.

This is absurd, of course. Each country should specialize on certain lines. If England made all the electrical goods, Germany all the fine chemicals, and the United States all the motor-cars, the world would get these three items much cheaper in terms of human effort expended. Nationalism is one of the chief enemies of mass production to-day.

Besides these non-technical irrationalities, there are two legitimate reasons for not concentrating whole industries in single plants in order to reap the full advan-

tage of mass production. Both are concerned with transportation. And both affect different industries to different extents.

All factories use raw materials and ship their finished product to market. If the raw materials used are heavy or bulky the plants are forced to locate, in relatively smaller units, near their sources. If they should concentrate under one roof, the cost of transporting the raw materials to the plant would cancel the advantages of larger production. This is why low-grade copper-ore, for instance, is generally smelted at the mine mouth. As far as the smelting operation itself is concerned, it would be more efficient to treat the ore of many mines at one central point. But the finished copper is much cheaper to transport than the raw ore. Therefore the smelters are placed as near the mines as possible.

When the finished product is harder to transport than the raw materials, the plants have to locate near their markets. Paper candy-boxes, for example, are usually made within reach of candy factories. Their cost could certainly be cut if they were all made in Boston or Birmingham, but the expense of shipping such bulky objects keeps the box factories from congregating under one roof.

Copper and paper boxes, however, are extreme cases. Their transportation problems are great, and the advantages of producing them in larger quantities by mass-production methods are relatively small. Most industries are much freer to concentrate where they choose. Factories producing small, expensive, complicated objects such as cameras, watches, or telephones have practically no transportation problem to solve. They do not use large quantities of heavy raw materials, and their product is very inexpensive to ship in comparison to its value and the amount of work expended upon it. There is no technical or transportational reason why all such

things should not be made in single efficient plants. And the advantages are enormous.

Motor-cars are in a slightly different position. They are not particularly valuable by weight. Popular-priced motor-cars do not cost as much per pound as top-round steak or smoked ham on the market. They are also bulky and difficult to ship. But the advantages of making motor-cars by mass-production methods are so overwhelmingly great that they outweigh all other considerations. An almost irresistible attractive draws the plants to within reach of Detroit. Every year a larger proportion of the world total comes from there. It is probable that if it were not for nationalistic tariffs, subsidies, and regulations not a single motor-car would be made outside the United States. The same set of conditions will certainly dominate the aviation industry as soon as it reaches the mass-production stage.

Other industries not seriously affected by transportation charges are electric refrigerators, machine tools, wireless, sewing-machines and typewriters. All such things can be produced more cheaply and efficiently in one locality each. Sufficient proof of this is that the factories making them *are* tending to concentrate except when prevented from doing so by artificial restrictions. If these restrictions do not increase, the plants will certainly become larger and fewer in the future and they will use much less labour per unit of product than they use to-day.

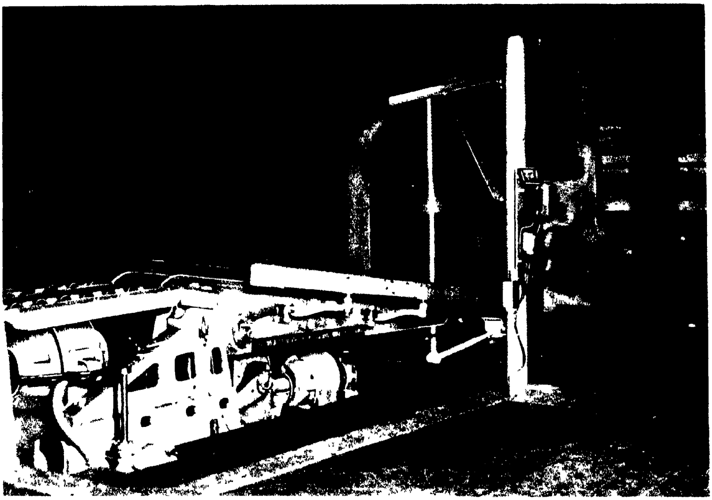
There is one more legitimate reason for not concentrating entire industries in single mass-production plants. It is also a transportation problem, although an indirect one. No matter how automatic a factory becomes, it always requires a certain number of human employees. These form a city around the plant, and the larger the city grows the harder it is to supply it with goods and services. Food has to be brought from a distance. Water the same. Space for houses and stores become

tage of mass production. Both are concerned with transportation. And both affect different industries to different extents.

All factories use raw materials and ship their finished product to market. If the raw materials used are heavy or bulky the plants are forced to locate, in relatively smaller units, near their sources. If they should concentrate under one roof, the cost of transporting the raw materials to the plant would cancel the advantages of larger production. This is why low-grade copper-ore, for instance, is generally smelted at the mine mouth. As far as the smelting operation itself is concerned, it would be more efficient to treat the ore of many mines at one central point. But the finished copper is much cheaper to transport than the raw ore. Therefore the smelters are placed as near the mines as possible.

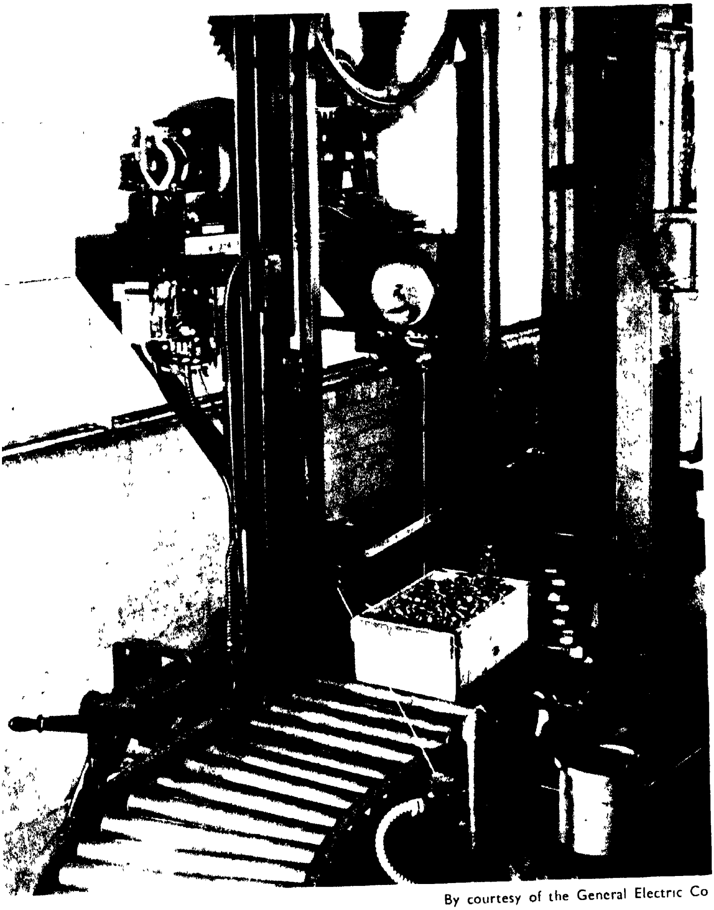
When the finished product is harder to transport than the raw materials, the plants have to locate near their markets. Paper candy-boxes, for example, are usually made within reach of candy factories. Their cost could certainly be cut if they were all made in Boston or Birmingham, but the expense of shipping such bulky objects keeps the box factories from congregating under one roof.

Copper and paper boxes, however, are extreme cases. Their transportation problems are great, and the advantages of producing them in larger quantities by mass-production methods are relatively small. Most industries are much freer to concentrate where they choose. Factories producing small, expensive, complicated objects such as cameras, watches, or telephones have practically no transportation problem to solve. They do not use large quantities of heavy raw materials, and their product is very inexpensive to ship in comparison to its value and the amount of work expended upon it. There is no technical or transportational reason why all such



By courtesy of the General Electric Co

A PHOTO-ELECTRIC CELL OPERATING A DEVICE FOR CATCHING HOT METAL SHEETS AS THEY COME FROM A ROLLING MILL. THE MECHANISM COMES INTO OPERATION WHEN THE VERTICAL BEAM (RIGHT CENTRE) IS INTERRUPTED



By courtesy of the General Electric Co

PHOTO-ELECTRIC CONTROL UTILIZED TO STOP VERTICAL LIFT WHEN TOTE BOX INTERCEPTS THE LIGHT BEAM THIS PREVENTS PILING UP OF BOXES LIGHT BEAM PLACED AT ANGLE TO TAKE CARE OF ALL-SIZE BOXES

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paint an idyllic picture of a small factory in a pleasant small town. The workers live cheaply on the food products of the surrounding farms and enjoy pure air, plenty of space, and sunlight.

These advantages are real, but until recently such small plants have not proved efficient. Most of them made a complicated product which required many operations to complete it. Their volume was small and so they could not achieve mass production by installing all the newest machines and keeping them busy. Consequently their business seeped away gradually to the efficient large plants.

But the tendency now is in the other direction. The small-town factories are learning to specialize very narrowly. If they do not undertake too much they can afford all the machines they need. They can often capture and handle all the available business in a single specialty and so enjoy all the possible advantages of mass production while retaining the advantages of decentralization.

Leaving out of consideration non-technical factors (tariffs, financial sabotage and blocking, disorganization caused by selling tactics), it is apparent that the transportation problem is the only unavoidable barrier which keeps us from realizing fully the advantages of mass production. The difficulty of transporting goods and men makes itself felt in two ways. First, it forces certain industries to locate near their markets or sources of raw material and so keeps them from concentrating. Second, it causes expensive and disagreeable congestion around the industries which so concentrate. A partial solution is to scatter small, specialized factories through uncrowded districts. But there is a transportation limit to this method also. If an article has to make too many short journeys before it is finished, the advantages of decentralization are eaten up by the shipping charges.

The cost of transportation, of course, is falling all the time—at least in terms of the human labour consumed, which is the only real measure of cost. If the railways persist in keeping their rates up, highways and waterways will take their traffic from them. Even aeroplanes, not usually thought of as freight carriers, may affect the situation in a minor way.

So the transportation problem, the one real enemy of mass production, is certain to lose a good deal of its effect in the future. When it does, and when the non-technical problems are also reduced, automatic machines will come into their own. Mechanical engineers are convinced that they can design machines to perform any operation, no matter how difficult or delicate. All they need is sufficient volume of output to justify the cost of the machines and keep them busy.

Rational concentration of industry will not give them this volume in all cases. We shall never see automatic-machine production of pipe organs, for instance, or of turbines for ocean liners. Too few will ever be needed. But most of the familiar objects we use to-day, as well as new articles not yet on the market, can be produced by automatic machines, and will be, if the engineers have their way. Their market prices may not fall. That will depend upon economics and politics. But their cost in terms of human labour will certainly be reduced to a small fraction of what it is now. The manufacturing plants of the future will give employment to many fewer men. We have only begun to find out what machines can do.

THE FUTURE OF HUMAN LABOUR

There are a great many people at present who profess to be alarmed at the sight of an automatic machine doing a valuable job without human aid. The more efficient the machine, the more alarmed they are. When they

see a die-caster doing more work and better work than a thousand foundrymen, they throw up their hands, shout "technological unemployment" and rush for the nearest exit.

I consider this an extremely silly way to look at it, and I believe that most men who deal with the realities of applied science agree with me. Machines possess no life of their own. They are not overrunning the planet like malevolent Martians or super-insects intent upon destroying the human race. Sociologists are fond of saying that we do not know how to control their activities. This is not true. What we do not know how to control are those men who use machines against the public welfare—mostly politicians and financiers. They are too intent upon maintaining intact a *status quo* which magnifies their own importance, to provide properly for human workmen who have been unjustly deprived of their livelihoods by the success of some new machine.

The point that should be remembered when considering the effect of machines upon human life is that no machine has ever come into use which could not perform for us some desirable act better than we can do it for ourselves. The patent offices are full of Rube Goldberg inventions to enable three men to do the work of one. If we used such machines in large numbers the world would be poorer. But we don't.

When a machine is invented, we subject it to a rigid test before we put it in operation. We ask, "Can it increase the world's supply of desirable goods and services at a lower cost in human effort?" If it cannot meet the test we do not give it life and it does not affect the situation. If it can, we use it, and the human race gets more for its labour. The unfortunate fact that a new machine often throws many men into unemployment and distress is not the fault of the machine or its inventor. The guilt is on the heads of those non-

technical leaders who fail to provide for the innocent victims of an improved method.

The increase of the machine population *ought* to produce more ease and security for the whole human race. The " standard of living " is the total supply of desirable goods and services divided by the number of consumers. Machines increase the supply. Therefore they should raise the standard, for the population of industrial countries is not increasing fast enough to keep up with them.

At present the introduction of a new machine does not always have this beneficial effect. It is apt to throw men out of work and into misery and want. The " technologically unemployed " *should* be human beings freed from disagreeable labour by the voluntary assistance of willing slaves. In actuality these unfortunates are often nearly freed from life itself. They protest against the machines, their natural allies, and try to run back into the slave-pen from which the machines have liberated them.

At present workmen are paid only when they can compete successfully with machines. This is the wrong way to look at it, for the competition in most lines of work is absolutely hopeless for the workmen. The human population should be thought of as plantation owners supported on the backs of slaves. When the slaves increase in numbers and efficiency, the human population should be able to live better. The well-being of a society should be measured by *how little* disagreeable work the people do, not by how much. " Re-employment " by the creation of unnecessary hand work is a banker's solution of the problem, not a scientific one. Its chief purpose is to keep the financiers and their allies in power. And it will not succeed, for it flies in the face of the strongest force in modern society—the constant multiplication of machines which are willing and able to produce for us the things we need.

I am not going to attempt to say how "technological unemployment" can be turned into a higher standard of living for all. That is a problem for those politicians, if any, who are conscious of what is going on in the world of science and industry. But I shall list the chief types of labour which will be required of human beings in the future—work which machines cannot do at present, and work which they will probably never be able to do.

Each industry passes through the same stages on its progress towards the ultimate goal of complete automaticity. I shall take metal casting as an example, although almost any other industry with its roots far in the past would serve as well.

Primitive metal casting was a handicraft, like the making of earthenware or cloth. The foundries were very small, and most of the workmen understood the whole process, from pattern-making to finishing the rough castings. They had to possess a certain amount of intelligence and judgment, for they performed many operations each. No machines were used.

Gradually machines began to creep into the foundries—very simple ones in the beginning. Water-driven bellows and grindstones probably came first. Then hoists and overhead cranes for handling large moulds and large amounts of metal. The foundries got bigger, for small shops could not afford the new equipment.

As soon as the machines arrived, two new groups of workers took their places beside the old-fashioned hand-workers and their bosses. They overlapped a good deal and still do, but they became more distinct as more machines were used.

In the first group were the highly skilled and adaptable men who set up, repaired, and adjusted the new machines. Their work was not in the least monotonous for they had to deal with emergencies, breakdowns, and all the novel problems which are constantly arising in machine-shops. The more machines, the more of

them, and the more able they had to be. They were a step up from the handicraft workers.

The second class was a step down. The early machines were seldom completely automatic. They required one or more human labourers to keep pace with them, feed them, oil them, clean them, and carry material around the shop. In the case of foundries these workers stoked the furnaces, pushed hand-trucks, and held the rough castings against rapidly revolving grindstones, brushes, or buffing wheels. Their work was repetitious and demanded little skill or adaptability.

Gradually both of these classes encroached upon the handicraft workers. As the shops increased in size, they could afford more machinery. Greater specialization became possible. The pattern-makers no longer made the moulds as well and poured the metal into them. The greater volume of output enabled them to stick to small specialized tasks, which became very repetitious and monotonous.

When this happened, the stage was set for further mechanization. Repetitious tasks can always be done better by machines than by men. So gradually machines nibbled away the specialized hand jobs. Devices appeared for pouring many castings at once, for packing sand around the patterns. Each machine needed attention from both of the new classes of labourer. They needed able men to supervise them, and they needed other men content to keep pace with them and help them with their work.

But always the total number of men per unit of product decreased. If it had not done so, there would have been no advantage in using the new machines. The machine-supervisors and the machine-servants were never as numerous in proportion to output as the handworkers they replaced.

The metal casting industry is a very complex one. There are foundries in all stages of development. But

the final stage is die-casting, described in a preceding chapter. Here we see the effect which almost complete automaticity can have upon the men employed in the plants.

Modern die-casting uses only one type of highly skilled hand labour. A small number of craftsmen are required to make the dies, which take the place of the pattern-and-mould combination. They work with various improved tools and they need a great deal of technical knowledge. But their work is neither machine-supervision nor machine-serving. They form a small island of old-fashioned craftsmanship in the midst of a highly mechanized industry. There are very few of them, for a die lasts a long time and produces an immense number of castings before it wears out.

The machine-servants have also decreased in numbers. Automatic die-casters require very little help in their work. The castings they produce are so nearly in finished form that much of the traditional grinding and polishing is unnecessary. The rest, if volume warrants, is often done by machines as automatic as the die-casters themselves. Since no sand, patterns, or moulds are used, there are few burdens to be carried around the shop. There are no furnaces to be tended, for the metal is melted in the machine itself.

But the machine-supervisors have not decreased in numbers. There are more of them than ever before. Expensive machines must be watched constantly by men who understand them thoroughly. They must be constructed and installed by highly trained specialists. They must be designed by technicians who use the discoveries of research workers. And the cheapness of the die-castings themselves is responsible in part for the existence of numerous other industries which employ the same high type of labour.

This shifting of labour requirements can be traced through all industries. Each step towards the complete

mechanization of an industry reduces the numbers of the old-time craftsmen. Simultaneously it adds to the pay-roll a small group of highly trained adaptable men whose job is to supervise the machines. Often another type of labour appears as well—the less adaptable, relatively untrained men who perform monotonous, repetitious tasks in conjunction with some machine or group of machines. They are needed only because the machines are not yet perfect enough or complete enough to work by themselves without help. Sometimes it takes only a very slight mechanical improvement to free such men from their disagreeable labour.

An excellent example of this final change may be found at the very beginning of the machine age. The first Newcomen steam engines required a " valve-boy ". His job was to open a valve to let steam flow into the cylinder. When the piston had risen enough, he closed the valve and opened another which allowed a water spray to condense the steam and let the piston fall. That was all he did, and there was not much mental effort involved. But eventually one of the boys rigged up a contrivance of strings and levers which made the overhead walking-beam open the valves at the correct moment in the working cycle. The engine then became completely automatic, and the boy lost his job. He probably got another job in the class of machine-supervisors, but there is no information on this point.

At present the machine-servants as well as the old-fashioned craftsmen are being eliminated rapidly. Something is certainly lost when a skilled handicraft goes out of existence, but no one should regret the passing of men who make a single set of motions all day long. Many of them seem to enjoy their monotonous jobs, so free from all responsibility and necessity for thought, but they are hardly an asset to society. A large part of the most hopeless " unemployables " who live on government bounty to-day are former machine-servants, whose

native intelligence and adaptability have been impaired by jobs which required only a few muscles and no mind at all.

Industry of the future will use only a very few craftsmen and comparatively few machine-servants. But it will use a great many more of those highly skilled human beings whom I have called "machine-supervisors". They range from university trained scientists and engineers down to garage mechanics. The quality which they have in common and which distinguishes them from other workmen is that they know how to *think*. They have to understand at least a few of the general principles of applied science. They have to use judgment. They have to meet emergencies and overcome novel difficulties. Their functions are not repetitious, and therefore cannot be delegated to machines.

As machines improve in quality and dependability, some of these men will not be needed any more. Motor-cars, for instance, do not get out of order so much as they used to, and therefore they do not need so many garage men to fix them. The same is true of aeroplanes, telephones, and machine-tools. This effect will continue, but it is not nearly keeping pace with the rapid development of machine civilization. Furthermore, skilled mechanics and technicians do not suffer fatally from unemployment when their jobs fold up under them. They are sufficiently adaptable to find places in allied lines. As long as machines cannot think, there will be work for men who can.

So there is at least one market for human labour which is growing, not fading away. The problem which machines present to the non-technical leaders of society is how to provide for those men who formerly earned their living by doing things which machines can do far better—the pick-and-shovel miners, the furnace-stokers, the machine-feeders, the oilers, the few remaining craftsmen who still try to cling to their diminishing trades.

Some of them can be raised by proper training to the status of " machine-supervisors ". Those who cannot respond to such training can " serve " the others in various ways—maintain recreation facilities, distribute the greater volume and variety of goods which the mass-production industries of the future are sure to produce.

One thing is certain. Only artificial restrictions enforced by the government will insure to incompetent men a permanent place in industry. The level of competence required is rising day by day. The number of jobs available for low-grade labour is falling. If the government chooses, it can restrict the hours per week during which machines are allowed to work. This will merely cancel most of their advantages and keep the advanced types from being installed. Or the government can limit the weekly working hours of the men to ten or fifteen. This will cause a shortage of " machine-supervisors " and—unless education can raise the level of adaptability—will force many unsuitable candidates into their ranks, which will also hinder progress. The machines of the future will need good brains to design, to build, to adjust, and to manage them. " The average man " as we know him to-day will not measure up to their requirements.

The social organization of the future will depend very largely on how we decide to solve this problem, and how well we do solve it after we have made the decision. Perhaps we shall not attempt to " give work " to every man. Work after all is not a thing which all men hanker after. Part of the population not engaged in economic production might enjoy being supported at a low standard of living. Perhaps we shall decide to segregate the unemployable on " subsistence farms ". There will be plenty of work on such farms, although most of it will be waste motion in view of the recent improvements in agriculture.

Another possible solution would be to pay the machine-

supervisors very highly so that they might employ many of their fellows as personal servants and indulge in recreations which involve much service. This might create a sort of intellectual aristocracy—a thing repugnant to the majority of the human race.

There are many other theoretical solutions, some of them more fantastic ; some of them less. But to choose among them is not the responsibility of the inventors and technical men. They have done their job very well. They have eliminated much physical drudgery and are rapidly reducing the remainder. They look forward to a day when men will work chiefly with their brains, not with their muscles. There will be plenty of every material thing, and a large amount of leisure to be distributed. At this point the technical men renounce further responsibility. It will not be their fault if " plenty " becomes " burdensome surplus ", or if leisure is turned into painful " unemployment ".

In the era which has just passed, we counted upon industry to take care of the surplus population of the agricultural areas. Farm boys went to the industrial cities and found employment there. But industry in the future, particularly manufacturing, will require fewer and fewer men. This is inevitable. It is already happening, and it need not alarm us unduly. Hunting used to be the chief occupation of the human race. Now it is a business for a very few and a recreation for a few more. We have solved completely the problem of how to cope with wild animals and turn them to our uses. The same in a less degree is true of agriculture. Everyone knows that a small part of the human race can raise food for all—a task which once occupied nearly the entire population. Manufacturing and transportation may finally fall into the same class. To design machines, run them, and play with them may some day be considered a pleasant avocation, like duck-hunting or raising prize flowers. Both of these are exacting jobs, but we don't look upon

them as disagreeable work. When factories become wholly automatic, it may be considered a valuable privilege to enter them and supervise the machines at their work.

WILL MACHINES LEARN TO THINK?

This is rather a philosophical question, but I have stated that engineers are confident that they can design machines to do any conceivable mechanical task. All they need is sufficient volume of production to justify the investment and keep the machines fairly busy. So it is interesting to speculate just what they mean by " mechanical tasks "—how far the word " mechanical " can be stretched.

It will certainly cover all the handicrafts. If we ever decide that we need ten million bass viols a year, automatic machines will be designed to produce them all complete, with their pitch and tone tested mechanically to any desired degree of accuracy. The same is true of every other object now produced chiefly by hand methods—from spectroscopes to ocean liners. There is no theoretical reason why a gigantic factory could not turn out the latter at any given rate as if they were motor-cars.

It is also possible—theoretically—that automatic machines could produce in turn the equipment and buildings for the bass viol and ocean liner factories. And themselves be produced by automatic machines. Thus it is possible to progress step by step into the most distant reaches of improbability without finding any theoretical need for hand labour.

But all machines, as we know them to-day, require a certain amount of attention. They have to be designed originally. They get out of order. They have to be started and stopped occasionally. They wear out and have to be replaced. These tasks are performed by the

highly trained and adaptable men whom I have called " machine-supervisors ".

Every advance in mechanical civilization has, so far, increased their numbers. They are primarily thinkers. The material work they do is merely incidental to their thought. They rarely do the same thing during two successive hours, and they never make a small set of motions over and over again for days on end. In scientific terms we can say that it is impossible to detect any " periodicity " in their functioning.

Therefore it is difficult to imagine machines which could do their work for them. Some of the lower grades of supervisors will be eliminated by improving the quality and dependability of the machines. But there would always remain plenty of jobs for thinking men with ability to reason and pass judgment.

But will the machines themselves learn to think?

Here we will have to take leave of practical problems and look far into the improbable future. It is certain that no machine in existence to-day can approach even remotely the human brain in ability to reason. No turret lathe can decide when it needs a new bearing. No cash register can pawn itself when the rent is due. No motor-car factory knows what kind of car the public is likely to buy or how many.

But certain scientists, nevertheless, incline to the opinion that the human brain itself is only a vastly complicated mechanism which responds mechanically to stimuli, like a cash register or a typewriter. They may be right. Perhaps there is no hard-and-fast dividing line between a typewriter deciding what to do when a key is struck and a human brain deciding to vote Republican. It may be only a matter of degree, one stimulus determining the first act, 10,000 the second.

If this is true—if the human brain is only an unusually intricate mechanism—then we can say that already machines have learned to think, after a fashion. They

merely differ in intellectual capacity. A calculating machine can think better than a typewriter, and the dial telephone system can think better than either.

In this case the machines may some day develop enough intelligence to control their own reproduction. They are already fathered and mothered partially by other machines, as a visit to a turret-lathe factory will prove. They may learn to supply themselves with everything they need. Their food—which is energy and metals—is already gathered largely by machines. Sufficient intelligence to govern themselves is all they lack. When they acquire it, they will be able to dispense with the human race entirely. They will possess the planet in actuality, as they already do in appearance.

But personally I do not believe in this possibility, even granting that it lies fantastically distant in the future. I think that the human brain is not only more complicated than any existing machine, or all the existing machines together, but is different in *kind*. Altogether different, and wholly proof against scientific analysis.

There are more mysteries abroad in the world at present than ever before. Higher physics becomes more baffling every year. We cannot define either space, or time, or energy, or matter, although a few years ago we thought we knew exactly what each term meant. There is even evidence that our most dependable measuring stick, the speed of light, is not constant but rises and falls in a definite cycle.

There are deeper mysteries still. We know almost nothing about non-material factors such as personality and consciousness. We suspect that "transference of thought" exists, but we cannot explain it or even study it. We do not know what "life" is, or death for that matter. The more mysteries we explain the more we find which demand explanation. We are making no progress towards explaining the universe in terms of mechanism. In fact we are losing ground.

So I do not believe that machines will ever dominate the world. Human intelligence will always be in control, until the human race disappears and its machines with it. In last analysis they are nothing but improved tools, the creations of our minds, the extensions of our bodies. They may reduce the numbers of the human race. That depends upon how we decide to regulate them. But they will not reduce the amount of intelligence in the world. They will increase the proportion of intelligent men by putting a premium on brains. The machine world of the future will have few places in it for the naturally stupid, except as state charges or playthings for the more gifted. They will have no useful functions. Machines can do their work.

But the intelligent may become as numerous as they decide they wish to be. The machines of the future will not require dull men to help them, but they will certainly require an increased amount of intellectual understanding.

I refuse to consider this prospect a depressing one.

VI

TRANSPORTATION

I HAVE tried to give the background of machines by tracing their history briefly. I have chosen a few adult machines—automatic ones—and described them in some detail as examples of what mechanical invention can accomplish when conditions are favourable. I have discussed mass production, which is the organization of machines into effective, co-operative groups, and have pointed out the various obstacles which keep it the exception rather than the rule in industry to-day.

Most of these obstacles are non-technical. They depend upon human failings such as nationalism, commercial selfishness, and our regrettable inability, or unwillingness, to reorganize our society promptly when confronted by wholly new conditions.

But there is one genuine and unavoidable technical factor which limits our use of mass-production methods. This is the difficulty of moving men and materials from place to place. Mass-production industries must be centralized in a comparatively few localities. They cannot be near all their sources of raw material and all their markets. Therefore they need transportation, for securing supplies and for shipping the finished product to the people who consume it. Their employees need transportation also, both for travelling to and from work and for getting their food and other necessities.

I have explained in the proper place the limiting effect of transportation difficulties upon mass-production industries. If transportation improves in the future, mass production will be used more widely. We shall

have the benefit of more automatic machines. Fewer men will do work which machines can do better. We shall expend less human labour in return for the material things we need or think we need.

So in the next sections I am going to consider the question, " How will transportation improve ? "

Reduced to simplest terms, transportation has only one function. It brings people in contact with physical environments which are out of reach of their personal powers of motion. But there are two ways in which it can accomplish this. It can take human beings to other locations where conditions for some reason are favourable. Or it can bring the products of distant regions back to the people who stay at home.

This sounds like the worst kind of generalization—too true to be important. But it is not. The two kinds of transportation, passenger and freight—although they often use the same facilities simultaneously—may have wholly different effects upon the distribution of the population and its mode of life. When passenger transportation is " ahead ", population tends to spread out over thinly settled regions. When freight transportation is " ahead ", people tend to congregate in large cities and thickly populated industrial regions. Of course there are other factors affecting this matter, but the balance between the two kinds of transportation is the most important.

In primitive, pre-mechanical society, " passengers " were much more mobile than freight. When population became too dense, a peasant family could move, on its own feet or with the aid of its own draft animals, to unoccupied land. When it arrived at the new location, it could produce from the land almost all of the things it needed. But if it stayed at home and attempted to earn a living by some sort of industrial enterprise, it had a much worse time of it. In the days of ox-carts

and pack-horses it was much easier to move the surplus population to the source of food than to bring food to overcrowded areas.

Therefore "pioneering" paid. Primitive populations tended to spread rather evenly over the available land. The cities remained small, for they had to get most of their supplies from near-by farm areas. There were no large communities of specialists, either agricultural or industrial. Specialization implies easy transportation to supply the commodities not produced on the spot. Primitive communities did not possess such transportation.

When the ancient civilizations developed, the situation changed only slightly. Fairly large cities appeared, but they did so in spite of the transportation factor rather than because of any notable improvement. Some of them were the governmental and military centres of large empires—Rome, Athens, Carthage. They were fed with great difficulty at government expense, and the cost was largely defrayed by tribute or taxation upon the outlying districts. Others—the cities of Egypt and Mesopotamia—got their food from near-by areas of exceptional, concentrated productivity. They could not have existed in ordinary farming country.

To some extent all the ancient cities benefited from waterway transportation, the only type which had improved appreciably from primitive times. But ships were still very crude. They could not sail against the wind. They were fragile and undependable. The Roman government, for example, had great difficulty transporting food from near-by Egypt. It never attempted to utilize the fertile lands of Britain or Northern Gaul. The food those provinces produced was consumed on the spot or not at all.

This situation continued into the late Middle Ages. There were a few governmental cities, but they were comparatively small. The population of Europe became

fairly dense, but it was rather evenly distributed, its density depending in general upon the fertility of the land and the skill with which it was cultivated.

Then came a development which changed the whole set-up. Ships learned to sail effectively against the wind, and they became sufficiently seaworthy to cross oceans instead of merely hugging the coasts and dodging into harbours whenever the weather looked doubtful. The ocean sailing ship is a composite invention. The most important elements are the keel, rudder, and movable sail combination which allows them to " beat " and the compass which guides them when out of sight of land. These two devices, combined with stronger construction, allowed them to go where they chose and to make much better time than ships which were forced to wait for favourable winds.

The sailing vessels of the sixteenth and seventeenth centuries put freight transportation, for the first time, ahead of passenger transportation—at least for long voyages. They could carry passengers across the ocean if necessary, but they were so slow that it was difficult to keep a large human cargo supplied with food and water. They were uncomfortable, unsanitary, and dangerous. Their development did not cause any mass migrations, even from the overcrowded countries of Europe. It is estimated that not more than 70,000 immigrants came to New England before 1700. Probably fewer Spaniards went to the Indies. The number of French and Dutch colonists was negligible.

The ships were much better at carrying freight, and in this capacity they affected the whole scheme of life in Europe and the New World. Surplus populations no longer had to seek new lands or starve. They could turn to industry and send out their manufactured products to pay for food and raw materials from less crowded countries. Cities grew larger, for they did not have to depend for food upon the farming districts

near by. Industry developed rapidly, even before machines became numerous, for a city specializing in a certain product could search the whole known world for markets.

Thus began the familiar division of the world into "industrial" and "raw-material" countries. We can look for other causes if we choose—the colonial laws, the mercantile system, political and military considerations. But these were secondary. The primary cause was the sailing ship, which could carry freight much better than it could carry men.

If we want to see the other side of the picture, we may look at the regions which did not feel the effect of this new means of transportation. The coastal portions of the New World were raw-material countries. They sent wheat, sugar, timber and other raw products by ship to Europe, taking manufactures in return. But only a few miles inland the previous conditions prevailed. Transportation was still so poor that inhabitants were forced to set up their own self-contained societies. Pioneering still paid. People still moved themselves bodily, from New England to Ohio for instance, instead of procuring from the new lands the products they could not raise at home. This was also the situation in eastern Europe, especially Russia, from which a stream of old-fashioned pioneers set out for Siberia, taking their goods and cattle with them and cutting practically all connection with their former homes.

Inland canals and waterways were another means of transportation which favoured the growth of cities. Canal boats are poor passenger vehicles, because of their extreme slowness, but they carry large amounts of freight very cheaply. The canals of western Europe allowed the inland cities to specialize in manufacturing and gave the peasants of thinly settled districts new markets for their products. In the United States the Erie and other canals pushed the "raw-material

economy" of the coast far inland into territory which previously had been forced by the lack of freight transportation to live on its own production.

The next important step in transportation was the railway. The early roads carried passengers with considerable speed and comfort, but they carried freight still better. At least their effect indicates that they did, for they intensified the specialization of countries and districts into "raw-material" and "industrial" areas. Cities grew larger. Hinterlands out of reach of ocean transportation or canals found themselves in touch with markets and sources of manufactured articles. The railways were responsible for the dense, overcrowded, unhealthy cities of the late nineteenth century. They brought food and raw materials easily and cheaply from distant sources, but they were not sufficiently good at passenger transportation to allow city workers to make their homes more than a short distance away from their daily work.

About the beginning of the twentieth century the tide turned. Passenger transportation got ahead once more. A series of developments took place which counteracted to a considerable degree the growing congestion of population in the specialized industrial cities. Among these were street-cars and rapid-transit lines. Later came motor-cars and buses. The railways themselves improved their passenger-carrying abilities by electrification which allowed them to make better time on short runs with numerous stops and starts.

As a result the cities began to spread widely into the surrounding country. They did not stop growing, for the advantages of centralized industry and trade were great, but their density of population began to decrease. Freight transportation built up the cities, gave them distant markets, and kept them in touch with sources of food and raw materials. Passenger transportation

thinned them out again. The familiar modern phenomenon of a great city with its central portion practically empty at night, the people living in distant suburbs, is due to this shift in the balance between the two types of transportation.

The present tendency is still strongly in favour of dispersion. Vehicles of every type are becoming faster year by year, and the time factor is much more important for passengers than for freight. Aircraft will continue the work of the motor-car and the rapid-transit lines. At present the average man can afford to live as much as 10 or 15 miles from his work. In the future this distance will certainly increase—perhaps to as much as 50 or 100 miles.

When this happens, the cities will lose substantially their present function as living places. They will become principally working-places, thronged in daytime but deserted at night. In countries such as England, where industrial cities are set closely together, the circular waves of population will spread out until they meet and cover thinly all the intervening space. The advantages of this are obvious. We can't live a modern life without centralized working-places, but improved transportation for passengers will restore to the industrial worker the clear air and sunlight of which he is often deprived to-day.

This, I think, is the most important effect which the transportation methods of the future will have upon our lives. We shall be able to concentrate our activities into larger and more efficient units, but we shall not have to pay as large a price in congestion as we do at present.

OCEAN TRANSPORTATION

We should expect no very important improvement in ocean-going ships either as freight carriers or passenger

carriers. There are two reasons for this, one technical, the other non-technical.

The technical reason is the familiar principle that when an object moves through a fluid medium it encounters resistance which is proportional to the *square* of the speed. The power consumed is proportional to the *cube* of the speed. To state it very simply, a ship which consumes 4,000 horse-power at 10 knots will use 32,000 at 20 knots and 108,000 at 30 knots. This law is not to be taken too literally. The shape of the hull is important. But it is unavoidably true that the power cost of high speed becomes prohibitive beyond a certain point.

In the case of cargo vessels this point was reached years ago. When a naval architect designs a freighter, he balances the advantages of speed against its disadvantages. Fast freighters make more trips per year. Therefore their capital charges and labour charges are smaller per trip. The shipper has to pay less interest on his cargo while it is afloat. Less food and water need be carried for the crew.

On the other hand each increase in speed demands a disproportionate increase in the size of the engines and in the fuel which they consume. This cuts down the amount of cargo which may be carried. Large engines require more and better men to tend them. The ship costs more to build and therefore has to bear higher capital charges per year.

These considerations vary in importance, of course, with the type of service for which the ship is intended. If she is going to carry perishable cargoes such as fruit, speed is more desirable than for coal or wheat. If the cargoes are very valuable—silk, for instance—the factor of interest on the goods carried will have more weight with the designer.

But for most freight vessels, the optimum speed works out rather low, something like 10 or 12 knots. Any

increase above this speed is a disadvantage which has to be paid for in some way, either by subsidies, mail payments, or a sideline of passenger carrying.

For passenger ships the situation is similar except that passengers are a type of cargo which weighs little and will pay for more speed. They consume a great deal of food and water, require a large crew to attend to their wants. Therefore an increase in speed not only attracts a larger passenger list but also lowers wage payments per trip, decreases the food and water item, and therefore reduces the dead weight which must be carried. These factors all tilt the balance towards greater speed.

But there is a definite limit even here. When the speed rises above about 20 knots the engines become so many and consume so much fuel that the advantages are cancelled. Passengers refuse to pay the necessary high fares and prefer to travel on the less expensive, slower ships.

We may expect, of course, a certain improvement in the building and designing of ships. Diesel engines are already dominant among new ships. They are comparatively expensive, but they cut the cost of the fuel and leave more room for cargo. If larger ships are built, they will be able to make better speed in rough weather without too much wear and tear. Aluminium is a rather untrustworthy metal for marine purposes, but if it becomes cheap enough it will be used in certain ways and will reduce the dead weight somewhat. Improved mechanical equipment will reduce the cost of the crew.

These improvements are minor matters which may make ocean transportation a little cheaper and a little faster. But they are greatly outweighed in importance by the non-technical factors which affect the speed of ocean-going vessels. It is a curious but undoubted fact that the speedier ships are already a great deal

faster than they have any legitimate reason to be. The heavy hand of nationalism has tilted the balance towards speed to an extent which the natural technical circumstances do not justify.

I said above that 12 knots was the present optimum speed for freighters and 20 knots for passenger ships. There are exceptions to the rule, but not very many. In general it can be said with confidence that almost all vessels which exceed these speeds are subsidized by their governments for nationalistic reasons. If this were not the case, ocean transportation would be much slower than it is at present.

These subsidies are granted for various motives. The "queens" of the North Atlantic are principally advertisements intended to increase national self-confidence at home and attract tourists from overseas. They do not make money, and no one hopes very seriously that they ever will. None of them would have been built without some form of government aid. Each major maritime country of Europe has invested in these gorgeous white elephants. France has the *Normandie* and the *Ile de France*. Italy the *Conte di Savoia* and the *Rex*. Germany the *Bremen* and the *Europa*. England has launched the *Queen Mary* and is planning a sister ship.

All these super liners have speeds approaching 30 knots, which they attain by cramming the hull with machinery and oil-bunkers. They have little room for freight—only for mail, passengers, and stewards and other servants. The rates they charge are high, but by no means high enough to make up for the increased costs. The passenger ships which make money are comparatively slow. If it were not for the international race for prestige, we should have no ships much faster than 20 knots.

As easy proof of the above statement, I can cite the fact that no 30-knot liner is plann'd for any run

except that between New York and Europe. The government-backed shipping companies hope to recoup their losses by operating slower, more practical vessels on the less conspicuous routes. If the fast liners were practical, they would have appeared running regularly to South American and Oriental ports long since. But they have not.

Subsidies are granted to fast freighters for slightly different reasons. They are considered valuable as naval auxiliaries and are given government support if they are fast enough to keep in touch with the fleet, outrun submarines, and act as transports in time of war. Most of the combination passenger-and-freight ships are in this class. A freighter fast enough to meet naval requirements is fast enough to carry passengers and mail. Most of the newer American merchant ships are of this type. Japan has a large number of them. England has so many genuine passenger ships which can do 20 knots that she is not forced to speed up her freighters artificially, but she will probably come to it soon. Many German ships, notably the *Bremen* and the *Europa*, are suspected of being cruisers in disguise, their framework being strong enough to support guns of considerable calibre.

This is the principal reason why ocean ships are not likely to increase their speed very much in the immediate future. Nationalistic rivalry has already pushed the existing speeds far above the natural level. Mechanical improvements will have to develop a long way before they can catch up with the ships designed in defiance of economic and technical principles.

Of course, if nationalistic rivalry continues to make itself felt, we shall see faster ships. They are theoretically possible. More power can be packed into their hulls by the use of high-speed, light-weight Diesels like those which drive the German "pocket" battleships. Ships

can be made to "plane" on the surface like fast motor-boats.

I do not think these things will be done. Certainly the treasuries of the maritime nations must hope they will not be driven to any such costly gestures. The future of high-speed transportation across the oceans belongs to the aeroplanes. They have already skimmed the cream of passenger traffic from a few of the routes. It is only a matter of time before they will have bettered the records of the fastest Atlantic liners by such a large margin that any increase in surface speed will seem ridiculous in comparison.

But ocean transportation is still by far the best means of moving inanimate burdens over long distances. It will probably remain so indefinitely. And there is one non-technical adjustment which would increase its utility vastly. Most ocean traffic is international. Its function is to supply each country with articles which are difficult or impossible to produce at home. This job it does very well, but it could do it much better if international trade were not strangled by self-cancelling tariffs and embargoes.

Ships cost practically the same to operate whether they are full or empty. Large ships carry cargo more cheaply than small ships. Transportation between one port and one other port is cheaper than between half a dozen ports at either end of the run. Therefore if a ship has to stop at several small ports and still manages to pick up only half a cargo, her rates will have to be set much above the ideal minimum.

This is the condition on many routes to-day. Small ports have to pay the high part-cargo rate or wait a long time until they have accumulated a full cargo. Often they are forced to send their goods to a larger port by expensive and unnecessary land transportation. If the reduction of tariffs should revive international trade, shipping costs would be sure to fall notably. Every

region of the world would benefit more fully from the special products of distant countries. That is what ships are for.

LAND TRANSPORTATION

Land transportation is not governed by the same laws as water transportation. Land vehicles move through a fluid medium, air, whose resistance increases as the square of the speed. But air is so thin that its resistance does not begin to be felt seriously until comparatively high speeds are reached—at least 50 miles an hour.

Much more important for land transportation is another type of resistance, friction between the vehicle and the ground which supports it. This resistance increases somewhat with the speed, but *not as the square of the speed.* Therefore it is the leading factor at low speeds, but falls behind the resistance of the air at high speeds. Surface friction can be reduced in two ways. The first is to equip the vehicle with wheels running in low-friction bearings. The second is to smooth the surface over which the wheels must pass.

The above set of facts is what makes speed on land different from speed on the water. Ships encounter no ground friction whatever. The smallest force, the strength of a child's arm, is able to move them through the water if the speed is low enough. But as the speed increases, the water offers more resistance until an excessive amount of power is required. The contrary is true of land vehicles. No child can budge a freight truck or even a motor-car. But if a force is sufficient to get them started, a slightly greater force will propel them over a smooth surface at considerable speed. Excessive power is not required until very high speeds are attained.

This is why ships are supreme for slow freight transportation. They move over a ready-made " roadbed " which is already as smooth as possible and which requires

no maintenance. The water offers serious resistance only to rapid motion. But land vehicles must be used wherever ships cannot go. A fairly smooth surface must be prepared for them in advance at great expense. But once they are moving over it, they can attain great speed before they encounter resistance from the air.

Ships may be considered separately, as self-contained units of transportation. But land vehicles must be considered in conjunction with the roadbeds prepared for them—highways or rails. The cost of these and the factors which limit their usefulness are at least as important as the vehicles themselves. So in weighing the future of land transportation I am not going to attach too much importance to potential improvements in motor-cars, motor trucks, or railway trains. Such things are interesting, but they are by no means the only factors. Earth-bound transportation is not as simple as that.

RAILWAYS

The railways are the slightly moribund senior partners of land transportation. They suffer from cirrhosis of the liver caused by financial high living in the past and aggravated by recent excesses. Their arteries are very hard. They are burdened by debt, legitimate and otherwise. They support a large number of parasites ranging all the way from entrenched labour unions to bankers' committees. They are slow to meet new conditions, quick to complain that the world, the public, and the government are against them.

In the past they were able to carry this heavy load because they possessed a technical monopoly. No other method of land transportation was efficient enough to compete with them seriously. Therefore they went the limit in over-expansion, extravagance, shortsightedness, and financial sleight-of-hand. By the time competition finally arrived in the form of highway and air transporta-

tion, they had become so accustomed to easy living that they were slow to meet the challenge, even to the extent that it was technically possible.

Recently the railways have shown signs of reviving vitality. They are trying to make their service conform to public preferences and are spreading a great deal of effective propaganda. Whether this is renewed youth or second childhood is hard to decide. The long-term technical trend is certainly against them. They will never regain their former dominant position, but they may be able to save a good deal from the wreck.

Considered abstractly, railways are a transition phenomenon. The function of land transportation is to carry freight and passengers from the point of origin to the point of destination. This is something the railways never hoped to do, even in their most optimistic period. Their rails could not be laid to every house, every farm, and every store. So they were forced to establish a limited number of stations and leave to the individual shipper or passenger the job of getting to these as best he could.

In many cases this arrangement was wholly satisfactory and remains so to-day. Certain mines, factories, and docks have large amounts of freight which they wish to send in bulk to a few destinations. Cities produce large numbers of passengers who want to go to other cities. The railways built up a network with sufficient meshes to connect most of these places with one another directly. Minor shippers were forced to use the railways too, although they often had to spend much money and effort to reach the stations. They had no choice. There was no other cheap and practical form of land transportation.

The railways reached the peak of their dominance about 1910. Practically everything which moved more than a few miles travelled over them. The territory between was a transportation vacuum. It was as if the

railway lines were separated from one another by Chinese Walls. If a load of freight originated 5 miles from a railway and was consigned to a point 20 miles away near another railway, it could not be sent direct. There were only 6,000 motor trucks in the United States. Wagon transportation cost too much. The equipment had to go by rail, often by an indirect route, and pay a certain amount of wagon haulage as well.

This situation was ideal for the railway. The traffic, both passenger and freight, was forced to come to them in exactly the form they could handle best—large amounts moving between comparatively few points. They had almost no competition as long as the Chinese Walls remained intact.

But the position had a fatal weakness. The railway lines could be short-circuited by any type of land transportation which would traverse the areas between them. This, of course, is what happened when trucks and motor-cars became practical and numerous. The impenetrable barriers between the railway lines fell to earth in a cloud of dust like the walls of Jericho. The railways hoped at first that the trucks would act as feeders and bring freight to the stations. But shippers soon discovered to their delight that in many cases they could eliminate the railway entirely and send their goods directly from its point of origin to its destination. No transfer charges at either end, no costly packing, no delays, no roundabout detours, no train schedules beyond their control. Just one quick run from factory to store or from farm to market.

This is the fundamental change which has reduced the railways to second place in land transportation. They will still carry bulk freight between two given points very cheaply—much more cheaply than trucks. They will still carry passengers from station to station more quickly and more comfortably than motor-cars or buses. But this is only half the job. Passengers do

not make their homes in railway stations, nor does the freight originate there. The patrons of the railways must reach the stations somehow, whether they are shipping freight or merely themselves. And once they have bought or hired a road vehicle they often decide to use it exclusively and save the trouble and expense of transferring to a train, even though the railway can deliver its partial service more cheaply than the motor-car or truck.

So the present problem of the railways is to make their " half job " of transportation so cheap and convenient that they can retain the traffic they hold to-day. Some of the railway executives talk of taking the offensive and winning back business from the trucks. No one thinks they can do this. But they can resort to certain modern expedients which will check the decline to some extent.

HOW THE RAILWAYS CAN FIGHT BACK

Before I try to list the possible avenues of improvement which lie open to the railways, I should like to place the so-called " streamlined " trains in their proper position. To state it very briefly, they are nine-tenths advertising to one-tenth technology. This does not mean that they are not important or successful. On the contrary they are the best advertising the railways have ever done and they have already repaid their cost several times over in terms of public relations. A great deal more money will be spent on what practical railwayites call " tin petticoats ". It is good business because it convinces the public that the railways are not technical fossils. But no amount of streamlining will help the railways do their job more efficiently.

It was the threat of aeroplane competition on long passenger hauls which led the railways to invest in streamlined trains. And quite appropriately from an

advertising point of view, they tried to make the trains as much like aeroplanes as possible. Streamlining is necessary in modern, high-speed aviation. Therefore the railways judged correctly that if they " streamlined " their trains, the public would assume that they had acquired some of the aeroplanes' virtues without sharing their disadvantages.

But streamlining can never be more than a very minor factor in the efficiency of railway trains. In the first place, the resistance which air offers to the motion of a train does not become important below a speed of some 60 miles an hour. At this speed it accounts for about 25 per cent of the power consumed by a ten-car train of conventional design. When all other conditions are favourable, radical streamlining can reduce this power consumption by about one-third, causing a power saving of not more than 9 per cent.

Conditions are almost never favourable for the obvious reason that railway trains do not always head into the airstream like aeroplanes. Even a slight side-wind causes the stream of air passing over them to slant, and this upsets the best system of streamlining. Eddies form on the leeward side which absorb much of the power.

Besides this, there is the roughness of the ground to be considered. If the ground were perfectly smooth, the under surface of the train would carry the air along with it without much resistance. But there is no practical means of smoothing the ties and ballast. Therefore beneath the train is a layer of turbulent air. The upper part tends to move with the train. The lower part tends to stay behind with the projections of the ground surface. The resulting friction uses up a great deal of power. If the designers were actually attempting seriously to streamline the trains, they would at least minimize this effect by " cleaning up " the under surfaces. But such improvements would be out of

sight and are therefore neglected for lack of publicity value.

Even if all the possible advantages of ideal streamlining under ideal conditions were actually realized, the saving of fuel (the only saving) would be comparatively unimportant. Fuel is a very minor factor in the cost of railway maintenance. It is far outranked by such inconspicuous items as right-of-way maintenance, equipment repairs, etc. The fuel saved by streamlining all passenger trains would be too small to feature on the balance sheet.

As a matter of fact, the fuel economy of the streamlined trains is not due so much to their streamlining as to their light weight. The reason for this is rather a long story.

Steam locomotives are not economical in fuel, but a great deal of power can be packed into one of them without increasing the "frontal area". Diesel locomotives are much more economical, but so far it has not been possible to make them very powerful without their becoming too big to pass through existing tunnels and bridges. The power required to draw a train over a long route at any speed yet contemplated is governed not by the "head resistance" of the air, but by the grades encountered along the way. Therefore large passenger locomotives have from four to five thousand horse-power, although they do not use more than a fraction of this except when they are pulling out of stations or climbing hills.

So, if you want to use Diesels, you must reduce the weight of the train. This is expensive, but it can be done by change of design and the use of aluminium alloys or stainless steel. The Union Pacific's newest train is built largely of duralumin and weighs only 210 tons as compared with about 700 tons for a conventional train of similar capacity. This allows a 900-horse-power Diesel engine to draw it over the grades. It is attractively

streamlined and very economical in fuel consumption. But practically the same results could have been attained by mere weight reduction sufficient to allow the use of a Diesel locomotive.

Incidentally, streamlined trains are by no means a new idea. They were tried in France and elsewhere as far back as the 'nineties. In 1900 the Baltimore & Ohio ran a six-car, cigar-shaped train from Baltimore to Washington. It made good time—82 miles per hour on the open road—and proved to be slightly more economical of fuel than conventional equipment. But in those days the public had not been educated by aviation to admire streamlining. So the cigar-train was abandoned.

In short, streamlining of trains is a fashion, not an important technical improvement. Whether it becomes a general fashion or not depends upon the reaction of the public. It is not very expensive to give a train or a locomotive a superficially streamlined appearance. If the public is attracted by sweeping lines and smooth exteriors, the railways will provide them. But if the trains of the future offer better service, it will be due to other improvements than streamlining.

So much for the beauty treatment of rolling stock. The railways can improve their competitive position in other more practical ways, and are doing so already, especially since the depression removed the last remnants of their complacency. Most of their genuine technical improvements have been inconspicuous and not very visible to the public eye.

Since 1924, for instance, the consumption of coal "per thousand gross ton-miles" has fallen from 165 pounds to 120 pounds. This is a decrease of 27 per cent. It was accomplished by a large number of small improvements in locomotive design and is far greater than the saving which would result if every train were radically streamlined.

Another important improvement is the increased speed of freight trains. It seems incredible, but ten years ago the average speed of freight from terminal to terminal was only 11 miles per hour. Now it is 16 miles per hour—a gain of nearly 50 per cent. This also was accomplished by many inconspicuous advances. Locomotives were built for longer runs at sustained speed. Switching yards were improved. Many stops were eliminated. The railways found that while the shippers would not pay much more for high speed, they would desert to the motor lorries if they did not get it. The trend is still strongly towards the motor lorries for many types of freight, but the loss of traffic has been slower than before the freights were speeded up.

The railways have also forced their employees to treat fragile articles more tenderly, and this has allowed them to relax to some extent their rigid rules about packing and classification of freight. They have lengthened their trains, cutting the labour cost per truck. They have descended from their lofty " come-and-get-it " attitude and have begun to deliver shipments by truck to their destinations. All these things have helped, although none of them are very exciting.

When we come to consider possible future developments in railways, we are forced to separate passenger from freight transportation. They are different problems and obey different laws. The shippers of the heavy commodities which are the railways' bread and butter are much less interested in speed than they are in cheapness. A mine or a grain elevator is content if its shipments reach their destinations in reasonable time. For them the only disadvantage of slow speed is a few days' extra interest charges, and this is a small matter. Even the shippers of perishable or valuable goods are content with speeds far below those of present passenger trains. If freight trains could average 30 miles an hour between terminals on long hauls, they would far outdistance

much truck competition. They would not be as fast in all cases, but the difference would be too small to offset the cheapness of rail transportation.

This is the goal the railways must set for themselves. There is nothing impossible about it—merely the partial application of passenger practice to freight trains. The reason why it has not been accomplished already is chiefly the economic factor. The railways are equipped with locomotives designed for slow speeds and with freight trucks which would pound themselves to pieces if drawn as fast as passenger trains. They cannot afford to replace them all at once with modern rolling stock, and the few fast freights they possess are greatly hampered in their operation by the presence of slow, old-fashioned trains on the tracks.

This is not a condition which will continue indefinitely. Locomotives and freight trucks wear out in the ordinary course of events, and they will be replaced by faster equipment. The new trucks will have low-friction bearings, better springs, and wheels which will not be so hard on the rails. They will be much lighter because of the use of certain inexpensive corrosion-resisting steels which have recently appeared on the market. If aluminium alloys fall in price to the competitive level, they will cut the dead weight of an empty truck by as much as 50 per cent.

Steam locomotives will not be abandoned or changed very much in design, but they will be lighter, more powerful, and more efficient. Brakes will be better, and improved switching systems will eliminate the jams which occur to-day at nearly every important junction point. Short-wave wireless will allow the train crews to communicate with one another and with the train dispatchers without stopping for telegraphic orders. This is a cheap improvement, but it will be very important when the trains are speeded up.

An average speed of 30 miles an hour does not sound

very exciting by modern standards. But it is almost a 100-per-cent increase over present speeds and will have a tremendous effect upon all industry. Factories will find themselves half as far away from their markets and their sources of raw materials. This will allow better co-ordination and therefore greater use of mass-production methods. Interconnected regions, such as the Detroit motor-car area, will increase in size, allowing more of the parts to be manufactured by mass production in comparatively small cities within the practical radius. Perishable foodstuffs will be brought from distant regions instead of being raised on inferior lands near their points of consumption.

These fruits of faster freight transportation by rail, and many more which might be listed, will cause a marked reduction in the amount of human labour which must be expended to attain a given standard of living. The weight upon society of inefficient factories, agricultural lands, mines, and centres of population will be lightened greatly. In fact, the social benefits from this rather inconspicuous improvement will be so great that the government of a rationally organized nation would probably be justified in building the necessary equipment at once as a public works project and donating it to the railways.

But, of course, no existing government is rationally organized to this degree. The "saving of human effort" would appear immediately as increased unemployment. Small, inefficient industrial units, now protected from competition by transportation barriers, would collapse and leave their workers without function or support. Farmers on poor lands would be forced to revert to the subsistence farming of the thirteenth century.

So it is probably just as well that we shall have to wait for our fast, inexpensive rail transportation of freight until the railways gradually acquire the equipment by normal means. But the improvement is on

the books. If it does not come through the railways, it will come through the motor lorries which are running almost neck-and-neck with the railways and do not suffer nearly so much from financial and traditional handicaps. If no new barriers arise, such as a governmental monkey wrench in the works, our freight transportation is going to improve at least 50 per cent in the next ten years. We had better realize this and see that the social benefits are not turned into unnecessary human misery. But that is not a problem for the technicians. They deposit it with their compliments in the laps of the non-technical leaders of society.

When it comes to passenger transportation, the position of the railways is much weaker. There is no doubt that they can carry certain types of heavy freight on long, direct hauls much more cheaply than the highways. They have at least this asset to depend upon, although it is not enough alone to support them in the style to which they have been accustomed. But there is practically no field of passenger transportation in which they are not meeting serious competition which promises to increase in the future.

Passengers demand and will pay for three things which the railways are not able to provide without great difficulty. First they want speed—an entirely higher order of speed from that demanded by the vast bulk of the freight. And second, they want convenience, which means frequent service. And third, they " originate in small lots " and demand to be taken almost to their individual homes.

The third requirement, " home-door delivery of passengers ", the railways have never attempted to meet, unless street-car lines be classed as railways, and the bulk of these have already been supplanted by buses. The first and second requirements, speed and frequent service, the railways can meet to some degree if they choose, but they rarely find it profitable to do so.

The chief reason for this is that the railways are primarily carriers of freight. Their passenger revenues amounted in 1932 only to about 14 per cent of the total. Very few of them have tracks devoted to passenger trains only. Therefore their freight trains, the backbone of their business, must be sidetracked whenever a passenger train overtakes them. The faster and more frequent the passenger trains, the more freights they will force from the tracks. This is why passenger trains have not increased their speed enough to mention in the last fifteen years. Back in 1920, when passengers provided about a third of the revenue, it paid to put the freights on sidings more often. But now freight is the dominant factor, and the freight trains must not be slowed down by having too many passenger trains pass them on the road. To some extent this change of emphasis is responsible for the recent increase in the speed of freight trains. More of them were given the right of way.

In spite of this fundamental difficulty, the railways can speed up their passenger trains if they want to, for advertising purposes if not for tangible profit. Below about 100 miles an hour there is little technical difficulty, especially on long, straight stretches. The tracks might have to be improved a little, but danger at the curves can be avoided by building the trains with lower centres of gravity. Such trains would probably be streamlined. "Tin petticoats" are not very expensive, they do no harm, and they seem to arouse an excellent public reaction.

But passenger trains with speeds of 150 or 200 miles an hour—fast enough to compete in speed with aeroplanes—will never be practical. They are not impossible theoretically; there is no reason why they should not equal the speed of racing motor-cars, 272 miles an hour. But they would involve so much expense and would interfere with slower traffic so seriously that they would have to charge rates much higher than the air lines.

The future of very high-speed transportation belongs to the aeroplanes. No earth-bound vehicles can seriously compete with them.

There are other more practical ways in which the railways can improve their passenger service. The biggest asset of passenger trains is their comparative comfort. This can be increased greatly at small cost. Air-conditioning is one method. It is easy to control the " climate " in a railway coach, for there is plenty of power available to run the apparatus. Artificially cooled trains proved themselves valuable during the hot summer of 1934 and they are sure to become almost universal. More than 2,000 have been ordered for 1935.

Pullman cars are being made over rapidly to give greater privacy and comfort. A great deal of attention is being given to decoration, easy riding, food and service. The railways reason correctly that while they cannot compete seriously with the air lines in speed, they can at least make their trains so agreeable to ride upon that most passengers will regret to abandon them. Increased comfort will also offset to some extent the cheapness of buses, the second most dangerous competitors of the railways on long hauls. Buses are becoming more comfortable too, but they will never overtake the trains in this respect. The railways are reconciled to losing the lowest-class passengers to the buses, but they hope that when economic conditions improve, there will be fewer hardy travellers to stand for the unavoidable discomforts of a long, slow ride over the road.

There is one passenger field in which the railways are still supreme and where they have the technical means to improve their position greatly when they get the money for new equipment. This is suburban commuting. The tracks radiating from large cities are cleared of freight during the rush hours, so the passenger trains can go as fast as they like. The speed of suburban buses is strictly limited by traffic conditions, and it will

be a long time before commuting aeroplanes are sufficiently numerous to affect the situation.

The speed of a commuting train which makes many stops is determined chiefly by its acceleration. Electric trains with motors on every truck have by far the fastest getaway. They are improving rapidly at present, and in the future they will be able to maintain schedules which will double the practical commuting area of most large cities. The effect of this upon the life of city workers is obvious. It is more exciting to talk about clouds of autogiros rising from city roofs to take the breadwinner back to his fireside, but long before this happens, the improved electric trains will have accomplished much of the same result.

I have given so much space to the railways because they are and will long remain the backbone of land transportation. They may be old-fashioned and not particularly exciting, but they have no rival at present in the business of carrying very heavy loads long distances at moderate speed between a limited number of points. Under favourable conditions one 5,000-horse-power locomotive can draw 7,500 tons of net freight—as much as 1,500 five-ton-trucks using fifteen times the horse-power. One such cavalcade would jam 30 miles of highway.

But all the other services which the railways have provided in the past are sidelines—doubtful ventures which were profitable for a time only because of a total lack of competition. Passengers, freight in less-than-car-load lots, feeder lines, all these things were deviations from the natural field of the railways. The fact that they were profitable before motor vehicles and aeroplanes arrived led the railways to invest large sums of money in facilities which are nothing but burdens to-day.

At present almost all passenger traffic is unprofitable, so are most of the less-than-car-load lots. So are

thousands of miles of low-traffic lines. The necessity of making up their losses adds greatly to the rates on long-haul freight. If the railways could abandon these activities to the trucks, motor-cars, buses and aeroplanes, they could carry freight at much less cost and with much greater speed and convenience.

If the railways were governed by technicians interested only in providing transportation at low cost, they would soon be free of these burdens. Perhaps half of the lines would be torn up. They have no chance of competing with the highways on a one-train-a-day basis. Most of the passenger trains would cease to run. Many of the stations on the remaining lines would be closed for good. Thousands of them do not attract enough business to pay the wages of the station-master. These changes would allow the rates on the main lines to be lowered greatly. They would speed up freight delivery by clearing the tracks of passenger trains and small stopping-points. The efficiency of the long-haul lines would probably be increased by at least 100 per cent.

But, of course, the problem is not as simple as that. The railways, like all elderly institutions of a semi-public nature, are entangled in a baffling web of vested interests, that ancient enemy of technical progress. They have to pay debt charges on all their facilities, whether obsolete or not. Political pressure keeps them from abandoning unprofitable lines and services. They are still afflicted with financial wizards in high places who regard them as sources of personal profit, not as a vital part of the nation's transportation system.

Eventually, nevertheless, the changes will be made, whether the securities-holders, the labour unions, the wizards, and the small towns like it or not. One method is "reorganization", a euphemism for bankruptcy. This will take care of the debt charges on obsolete lines and equipment. Another is for the railway companies themselves to supply bus and truck service, frankly

abandoning the rails. The labour unions are gradually losing their power to force the railways to provide unnecessary employment. As for the wizards, they are already leaving for happier hunting grounds.

The next ten years will be a dismal time for the traditional widows and orphans who hold railway securities, for the crews of empty trains, for flagmen at one-train crossings, for high-salaried vice-presidents with light duties. But out of the wreck we shall get much better rail transportation of freight than we enjoy to-day. This is not as exciting as "streamlined" trains speeding across the continent at aeroplane speed, but it is vastly important, and it is bound to happen.

HIGHWAY TRANSPORTATION

We think of motor-cars and motor lorries as ultra-modern and up to date. And so they are. But we should not forget that their chief advantage is their fundamental simplicity. They perform their transportation job in the most direct way. They take their cargo from its point of origin to its destination. This is something railways can do very seldom, and even then only with the aid of very complicated apparatus—switch-yards, signalling devices, sidings, etc.

Motor vehicles are a part of the modern "return to simplicity" which is being felt in many lines. They may be compared to the die-casters which make in one motion a complicated product which formerly involved a dozen operations. Like many simple things, they were hard to develop.

If Leonardo da Vinci had been given a good engine to apply to land transportation, he would have built some sort of power wagon to drive over the roads of northern Italy. He would never have imagined a modern railway system with its vast investment and intricacy. "Perhaps later," he would have said, "when we have

enough traffic to justify such smooth steel roads. But not now."

No light, powerful and dependable engine was available, however, until about 1900. Therefore land transportation was forced to economize its power by building extremely smooth roads with easy grades and few stops. The only material smooth enough was wrought iron, soon replaced by steel. Since this was expensive, it was laid in the form of narrow rails, not broad roads. Even these were expensive, and so could not be laid down except on routes which promised a fair amount of traffic.

These exceedingly smooth steel roads, designed to reduce surface friction to a point where it could be overcome by the feeble power available, had various disadvantages which are still responsible for the trouble of the railways, explained at length in the preceding section. In the first place they did not go everywhere, and so never did more than half of the transportation job. And second the fact that trains could not pass one another on the open road required a complicated and expensive system of switches, sidings, double tracks, signals, and other auxiliaries. The railways, in fact, sacrificed everything to power economy.

When light petrol engines finally arrived, they cut through this tangle of hitherto necessary complication and restored land transportation to its normal simplicity. Lorries and motor-cars run better on expensive concrete roads, but they will travel over cart tracks or prairie if they have to. They need no switches, yards, sidings, or telegraphic signals. In most cases they will go to where the loads originate and take them directly to their destinations. Railways still possess the fundamental advantage for which they were designed. They will carry large amounts of freight with less expenditure of power and labour. But they should be looked upon as a special form of inflexible and expensive highway, justified only where traffic conditions are unusually favourable.

Proof of this may be found in the fact that practically no railways are being built at present except for military or political reasons, while highways are being extended rapidly in all parts of the world. Now that we can put a hundred horse-power conveniently under the hood of a motor vehicle, we find that we can dispense very largely with rails and their complications. If we had had a proper source of vehicle power in 1850, we should have built only a few low-resistance steel roads. Power economy was necessary then. It is still desirable, but not absolutely necessary.

We can already see the results of this change. Regions which attained their industrial maturity during the period of railway supremacy took on an appearance which will look very strange in the future. Where the rails went, life and growth followed. The areas away from the lines either declined or ceased to develop. Population tended to concentrate in beads and bands along the railways, while equally agreeable and productive regions a few miles away fell far behind. A map of 1900 which showed accurately the density of population would not need to trace the railway lines. The dark streaks and blotches of dense inhabitation would betray their locations.

By now, of course, this has changed radically. Motor vehicles with their ability to pass over very poor roads have restored to their proper positions many of the towns and agricultural regions formerly handicapped by lack of rail service. They have spread population more evenly. They have enabled isolated farmers to enjoy the cultural advantages of town-dwellers, and have given townsmen a chance to move out into the country if they choose.

The most striking effect of highway transportation has been upon countries which never possessed more than a few scattered railways. In Latin America, for instance, makeshift highways quickly and cheaply constructed of local materials have brought whole provinces overnight

into contact with the world. Their people have jumped suddenly from the sixteenth to the twentieth century without being forced to concentrate along narrow railway zones. The same has happened in other countries, such as Persia, Arabia, East Africa, and the Philippines.

Thus in two different ways motor vehicles have checked and to some extent counteracted the effect of the railways upon the distribution of population. First, they carry freight in comparatively small lots as cheaply as in large lots and over poor roads almost as well as over good ones. This makes it unnecessary for people to crowd around the transportation lines in order to get their goods to market. And second, they carry passengers so well and so easily that fewer people are forced to live in congested centres near their work. They have put passenger transport definitely ahead once more. The spreading of city suburbs and the development of backward regions " off the railway " are proofs sufficient.

In the future motor transportation will improve in various ways and increase its effect upon human life. I wish the improvements were going to be purely technical. They would be easier to describe. But such is not the case. Motor-vehicle manufacturing is by far the most modern and advanced of all the mass-production industries, but it has become so entangled in commercial problems that it cannot, or at least does not, supply the public with motor-cars at anywhere near their possible minimum cost or their maximum efficiency. The improvement and cheapening of highway transportation depends more upon correcting this situation than upon any likely mechanical developments.

THE FUTURE OF HIGHWAY TRANSPORTATION

I am not going to spend much time on the ultimate top speed of motor-cars. It is a subject which should

be of interest only to small boys and men with small-boy mentalities. I invite such persons to take a new Ford V-8, start it in motion on the finest highway in the vicinity and try to keep the accelerator pressed down to the floor for fifteen consecutive minutes. If they survive this simple experiment, they will realize very clearly that the speed problem has been solved so far as the car itself is concerned. We can increase the "speed" of our highways if we choose, but until we do, we shall not be able to use the speed which even the cheapest motor-cars already possess to-day.

Far more important than top speed is the question of cost—first cost, upkeep, and fuel consumption. There is obviously room for great improvement here, but when we try to estimate the possibilities, we plunge at once into the vastly complicated subject of price in a mass-production industry supported by a public which is always uninformed and usually misinformed as well.

If motor-car companies were run by sincere technicians intent on providing the world with the best and cheapest vehicles, we might know where we stood. But when an automobile engineer climbs up into the inner sanctum of the head office—as many have—he is forced to change his psychology. His problem is no longer how to supply the best and cheapest highway transportation, but how to extract the largest possible sum from the public purse.

This condition, necessary of course under present conditions if the stockholders are to survive, has produced some very curious results. First is the remarkable fact that the cost of selling motor-cars ranges from 40 to 75 per cent of the list price, the higher figure applying to expensive cars which have to pay for a large amount of advertising and promotion per unit. The manufacturers have learned by experience that a persuasive dealer on the spot in every small town, nourished by high commissions and backed up by floods of inspirational advertising, produces more sales than any reduction

in price which could be accomplished by eliminating him. All this effort, of course, is pure waste from a technical point of view, and a burden upon society. But so far no motor company has been able to survive without it.

Another curious fact is that there is at present no cheap car on the market. That is to say, there is no car which attempts to fill ordinary transportation needs at lowest cost. Many of the cheap fast cars are really luxury cars. More than half of their manufacturing cost represents excess horse-power which will never be used, gadgets with sales-appeal but small utility, extra cylinders to give "smoothness," and expensive finish and upholstery to appeal to the feminine buyers who judge motor-cars as they judge clothing and millinery—by their approach to ideals formed in their minds by style propaganda.

The reasons for this are purely commercial. The advantages of large-volume production are so overwhelming in the motor-car business that the cars which are manufactured in the largest numbers create a no-man's land both above and below their price range. Small volume competitors who sell at a slightly lower price must make their cars vastly inferior to compensate for the disadvantages of producing them in small lots. Similarly the high-price competitors cannot build better cars in small lots unless they charge a great deal more.

This situation allows a large-volume manufacturer to outdistance competition over a broad band of price ranges. It accounts for the fact that many engineers consider the Ford V-8 the best machine which can be bought at any price. The two other large-volume cars in the Ford price range are also outstanding. Most technicians are agreed that if you buy a car which lists lower than these three, you get a much inferior article which is only a little less expensive. And you have to pay nearly twice as much before you get a car which is

appreciably better except in certain featured details. These gaps are caused by the advantages of large-volume production.

Such being the case, the big manufacturers are not over-anxious to bring out "utility cars" at greatly reduced prices. To do so would deprive them of the new-car buyers whom they can now force to pay £100 or more. And furthermore, it would hurt the market for used cars and so make owners less willing to turn them in for new ones. The net result, the manufacturers fear, might be that the public would get its cars for a smaller total payment per year—excellent for the public, but bad for the manufacturers.

Therefore big manufacturers, as if by agreement, have competed in luxury, not in price. By elaborate and subtle advertising they have made the new-car public willing to pay for more quality and performance than it needs. As engineering and manufacturing methods improve, they add horse-power, finish, and mechanical novelties. But they do not reduce the price. So at present there is on the market no cheap "utility car" suited to people of small means. The poor man must buy either luxury, shabby and shaky luxury, or nothing. It is rather as if clothing manufacturers had abolished overalls in order to force farmers and labourers to wear tailored woollen suits to work.

These two factors are holding up the price of motor-cars to-day—"selling costs" to pay for propaganda and myriad dealers, and the deliberate decision of the manufacturers to concentrate on a middle price range. Needless to say, this is a rather unstable situation in a business as competitive as the motor-car industry. The manufacturers know, and it probably gives them sleepless nights, that a large section of the public would jump at the chance to buy a new "utility car" at £40. There is nothing impossible about this figure. The car would be at least as good as the Model-A Fords which are

still giving excellent service after four or five years of use. A simultaneous cut in selling costs—by mail order distribution, perhaps—might reduce the price still more.

It is not possible to predict when this " break " will take place, if at all. But many informed men are of the opinion that it may not be far away. One favourable factor is the tightening-up of the used-car market. When the depression began to be felt strongly in 1930, millions of cars were for sale at low prices. Those who had any money at all could get a fairly good car for the price of insurance, number-plate, and a month's petrol. But now the supply is largely exhausted. Prices have risen sharply and the low-income public is again in the market for cheap, new cars.

Another factor favourable to the appearance of such a car is the potential importance of the export trade in motor-cars. Most foreign buyers have not been educated up to American standards of automobile luxury. They want transportation at low cost and are practically certain to support with their orders any company which provides it. This is particularly the case in rapidly developing countries with low standards of living, such as Latin America, the Near East, and Asia. There is a strong foreboding in the motor-car business that if Detroit does not give this market what it wants, the Japanese will.

So much for the " first cost " of motor-cars. The situation in regard to upkeep and fuel consumption is somewhat similar. Present-day cars wear out much more quickly and use much more petrol than they should. Proof of the first may be found in the durability of large- and medium-sized trucks. These are built to last because they are bought by men who know their business. They often run 400,000 miles without showing fatal wear. But passenger cars are not nearly so durable. The manufacturers have no reason to make them so. They count on causing style changes by means of advertising which will lead many owners to

replace their cars long before they wear out. "Resale value", the measure of durability, is not one of the things which prospective car-buyers usually inquire about. The manufacturers take deliberate advantage of this carelessness, economize on wear-resisting features, and so ensure themselves of a larger annual replacement market.

It would not be at all difficult or expensive to make motor-cars which would keep in good condition twice as long as they do to-day. Cheap, rust-resisting steel in strategic places would help a great deal. Valve and cylinder inserts of specially hard metal could be used more widely, as they are in lorries. Wiring, switches, insulation, and other small electrical matters could be improved at slight cost. Better provision could be made for the quick and cheap replacement of worn moving parts. These minor changes would reduce very greatly the final cost of motor transportation, but the manufacturers will not make them until they are forced to do so by a greater public interest in durability. They are living to-day on the "replacement market", and they are afraid of killing it.

Fuel economy is another factor which is impossible to separate from the non-technical considerations which govern the motor-car industry. There is no doubt whatever that present-day motor-cars use much more petrol than necessary. This is not the fault of the engineers who design the cars. They have shown what they can do in the case of certain lorries, which now consume only one gallon of petrol for every hundred ton-miles under test conditions. The 1934 Pontiac, considered very economical, got only 39·7 ton-miles to the gallon on a smooth, level road at 25 miles per hour. Lorries are almost three times as efficient as passenger cars.

The reason for this difference is chiefly in the size of the engine. Lorry buyers demand fuel economy and get it, just as they get durability. They do not mind if

still giving excellent service after four or five years of use. A simultaneous cut in selling costs—by mail order distribution, perhaps—might reduce the price still more.

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by the cost of operation. They can buy cheap second-hand motor-cars, but they can't pay for the petrol to run them. A £40 motor-car which consumed as much fuel as the present makes would be subject to the same market limitations. Therefore when cheap cars finally arrive, they will probably be very economical of fuel as well. So the fuel consumption of the least expensive motor-cars of the future will depend on this "break" more than upon any mechanical improvements designed for fuel-saving.

I have spent much space on these semi-technical factors—style, popular preferences, and commercial considerations—because they dominate the motor-car industry at present. They must be understood clearly before it is profitable to discuss mechanical improvements which are likely to be made in the future.

The reader has probably wondered why I have not mentioned "streamlining"—the "airflow", "airstream", "tear-drop", and "Dymaxion" cars which seem to fascinate mechanical prophets. It would be too much to say that they are not worth mentioning, but like the "streamlined" trains discussed in an earlier section, they are nine-tenths advertising to one-tenth technology. They are chiefly interesting as proofs that the designers of motor-cars are dominated by the sales departments.

There are two key facts to remember when discussing "streamlining". The first is that the resistance of the air is important only when a vehicle is moving very rapidly. Up to 35 miles an hour it need not be considered at all. Up to 50 miles an hour it accounts for only some 30 per cent of the power consumed by motor-cars of ordinary design. This subject is very controversial, but I have given liberal allowances for error.

The second fact is that the public is not interested at present in fuel economy. If it were, the manufacturers would alter their designs slightly and cut the petrol consumption in half without resorting to any radical

changes. The fuel savings which may be achieved by means of streamlining are very small in comparison.

Motor-cars are affected more by air resistance than trains because they are shorter in comparison to their width, but the same general rules apply to both. Cross-winds destroy largely the effect of the best streamline design. The drag of the ground air cannot be eliminated. And in addition there is the fact that motor-cars must have engines sufficiently large to be strong enough to overcome the resistance of poor roads. A car might possibly be streamlined so that it would be able to run at 80 miles an hour over a good road with excellent fuel economy, but this could be done only by reducing the size of the engine. Then the car would not be able to climb hills, accelerate rapidly, or maintain even moderate speeds over bad surfaces. Proof of the importance of this factor may be found in the fact that the most radically streamlined cars on the market to-day have engines even more powerful than their non-streamlined predecessors of the same make.

As a matter of fact, no streamline design in use to-day reduces the head resistance appreciably. At 60 miles an hour the 1934 Chrysler " airflow " sedan met only 13 per cent less resistance than the Chrysler 1932 sedan of conventional design, and it made this saving only under ideal conditions which are rarely encountered. At ordinary high speeds it would save perhaps 8 per cent of the fuel. Much better saving could be accomplished by periodic adjustment of the carburettor or better attention to tyre inflation.

If the Chrysler company were really concerned with cutting the head-resistance, it would " clean up " such important details as the radiator cap, the tail-lamp, the rear number-plate, and the spare-tyre carrier. These probably cause more " parasite resistance " than is eliminated by the whole change of body design. But even if the car were as perfectly streamlined as a modern aero-

plane, which is impossible, the fuel saving at the highest practical speed would not amount to more than 15 or 20 per cent—too small to bother with.

The real reason behind the new streamlined cars is commercial, not technical. The manufacturers who go in for it are trying to change the style in motor-cars and so force the buyers who purchase for prestige to replace their conventional cars with streamlined models. Parisian *couturiers* do the same thing annually when they bring out their new dresses. It may work. If so, we shall have streamlined cars, perhaps even cars with engines in the rear. A radical modification will be necessary before efficient streamlining can be achieved. But the results will not be important unless other improvements happen to go with the streamlining.

Diesel engines for motor vehicles are another advance much discussed in the motor-car business. The general consensus of opinion seems to be that they are not worth the additional first cost under present conditions. Diesels are certainly more efficient as far as fuel economy goes, but they are more expensive to build. They are not as flexible and therefore do not have the ready supply of excess power demanded by the public. They will certainly come into use in large lorries, whose owners add up their fuel bills carefully. But they will not be used in passenger cars until the buyers show a great deal more interest in fuel economy and less in acceleration, smoothness, and top speed.

One of the most important advantages of Diesels is that they use cheap fuel oil instead of petrol. But such oil is cheap only because it is a by-product for which there is no sufficient market. The refiners are forced to sell it for consumption in heating apparatus and power plants. If motor-cars should take to using it in large quantities, the price would rise towards that of petrol. This is an additional factor which keeps the motor manufacturers from adopting Diesels.

Besides the various improvements which the manufacturers could make if they wanted to, there are several which they are eager to make but at present cannot. Aluminium is used in motor-cars only to a very limited extent, chiefly in the engine itself. It is too expensive for the bodies or the frame. But if the metal comes down in price as a result of a change from the present effective monopoly, it will be used much more widely. Its light weight will allow a smaller, cheaper, and more economical engine to produce the same results, and its resistance to corrosion will add to the life of the car.

Just when this advance will take place is impossible to predict, for the price of aluminium is supported by social and financial forces not under the control of technology. But it is significant that the Bohn Aluminium Company, which proposes to challenge the virgin aluminium monopoly, is a leading Detroit manufacturer of light-weight pistons and other automobile parts. There is at least a chance that the motor-car manufacturers themselves are standing behind it.

Other important improvements are apt to come about as by-products of streamline styling. Streamlines will not save an appreciable amount of fuel, but they may demolish the public's conviction that motor-cars should "look like motor-cars". That is, that they should look more or less as they do to-day. The designers would ask for no greater gift than a change of style radical enough to throw the public into utter confusion about what a motor-car "ought" to look like. They feel that before another fixed idea had time to take shape they might get a chance to rearrange the whole machine more logically.

At present the designers are greatly hampered by the position of the engine. The public is convinced that cars with long hoods in front "look powerful," although some of the hoods cover nothing but short V-type engines

and a great deal of empty air, which wastes space where it is needed most. The drive shaft passing under the floor-boards keeps the centre of gravity high. The rear seat has to be near the rear axle, although this is the roughest-riding part of the car. There are other minor difficulties. But so far no large manufacturer has had the courage to bring out a rear-engine car. The public, they are sure, would condemn it as " funny-looking ".

Streamline styling may change all this. A motor-car with the engine in the rear could have the blunt-nosed, tapering shape which the public is learning correctly to associate with streamlining. So the new popular interest in aerodynamics, stimulated by proper advertising, may get a " funny-looking " car accepted as an " ultra-modern " one.

The advantages of this reform would be considerable. Progress always results when an artificial restriction is removed. The elimination of the drive shaft and the troublesome universal joint would allow the centre of gravity to be lowered. This would not only increase the factor of safety on curves, but would lower the roof and so cut the head-resistance more than any streamlining would be likely to do. The removal of the engine to the rear would open all sorts of possibilities. The engine might lie on its side transversely under the back seat, occupying space which is wholly wasted to-day. Fumes and heat would be carried away from the passengers, not past them. Noise and vibration would not be nearly as noticeable. Visibility would be improved vastly, an important consideration in high-speed driving.

This is the chief reason to hope that the " tear-drop " car will succeed in capturing the public's imagination. The smooth, flowing lines will not, in themselves, represent important progress, but they will conceal the violent hands being laid upon popular prejudices. The new cars will be more efficient, and the streamlines will probably get most of the credit, although their direct contributions

will be extremely small, chiefly a minor reduction of wind noise.

So far I have ignored the question of high-speed driving. Present-day motor-cars can already move a great deal faster than road conditions will permit. Those few drivers who do " let her out " on the public highways should be placed firmly under lock and key. They are responsible for the majority of the accidents which have raised motor-car fatalities into the front rank among causes of death in motorized countries.

But nevertheless the average practical speed of motor-cars is going to increase because the public demands it. The cost will be tremendous. Each increase of speed adds disproportionately to the expense of highway construction. The wider the spread of speed between the fastest and the slowest traffic, the more passing there has to be and therefore the more chance for disaster. If motor-cars become really cheap and economical, there will be more of them ; they will be used more constantly and will congest the highways to a degree undreamed of to-day.

There are various ways in which the problem can be attacked, but they all have their limitations. I shall start with the cars themselves. As I have said several times above, they have plenty of top speed already. The problem now is how to make them stop fast enough when the driver sees trouble ahead.

The stopping time of a motor-car is determined by two factors. First comes the driver's " reaction time ". Human nerves are not instantaneous telegraphs. There is always an appreciable lag between the instant when an image is formed in the eye and the instant when the appropriate muscles come into action. The driver sees danger ahead—another car blocking his traffic lane, perhaps—but a certain amount of time elapses before his foot begins to press the brake pedal. This period varies greatly among individuals, but it is always present. It

increases with fatigue. One second is a fair average figure, although not a conservative one.

While this time is elapsing, the car moves on with undiminished velocity, and the distance covered is directly proportional to the speed. At 30 miles an hour the car covers 44 feet before the brakes are applied. At 60 miles it covers 88 feet. At 90 miles 132 feet. Nothing will ever be done to reduce this delay. It depends upon human factors entirely beyond our control.

But that is not the worst effect of increasing speed. When the driver finally applies the brakes, the car does not come to a halt at once. It slows down gradually, and covers additional distance which is proportional not to the speed but to the *square* of the speed. Thus if a car travelling 30 miles an hour can stop 50 feet from the point where the brakes were applied, it will require 200 feet at 60 miles an hour and 450 feet at 90 miles an hour.

We can reduce this distance somewhat, but not much. There is no limit to the strength with which the brakes may grip the wheels, but there is a very definite limit to the friction between the tyres and the road surface. Larger and softer tyres will not help in the slightest. Neither will increasing or decreasing the weight of the car. Making the tyres of a substance with a higher co-efficient of friction would help a little, but we are extremely unlikely to find such a material which is suitable in other respects.

The only possibility left is to roughen the road surface so that the tyres can get a better grip upon it. This is being done to some extent already, especially on express highways designed for high-speed traffic, and it will be done more widely in the future. But it offers only a slight advantage. We shall have to become reconciled to the principle that the safe stopping distance increases *more rapidly* than the speed. Now let us see what this implies.

To begin with, it means that the distance which must be maintained between vehicles moving in the same direction increases faster than the speed of the vehicles. This *reduces* the carrying capacity of the highway with each increase of speed. If 10,000 cars try to drive away from a football game over a perfect, straight, and unobstructed highway, their passengers will get home quicker on the average if they drive 30 miles an hour than if they space themselves so that they can drive at 80. The optimum speed varies with the distance to be covered and the number of cars to be accommodated, but it is never as high as the top speed of present-day motor-cars.

The final result of this set of facts is that high speed increases congestion instead of reducing it. Many motorists wonder why the police don't force Sunday-afternoon traffic to move faster and so clear the road. This is the reason.

The only way to avoid this effect is to build more highways so that their combined carrying capacities at high speed will equal the demand. In itself this is expensive, but the new highways must also be wider, straighter, and less obstructed by crossings than the old, for even the driver of an occasional car travelling at high speed on an empty road must be able to detect trouble a long way ahead. And if the "troubles" such as curves, crossings, and slow-moving lorries come too closely together, it will not be possible for him to travel at high speed without risking his own life and the lives of others. Needless to say, such express highways are extremely costly, but they will have to be built, and in large numbers, if we want to increase our driving speeds without seeing motor fatalities become the commonest kind of death.

Practically, then, we shall have to superimpose an entirely new highway system upon the old. It will be devoted strictly to high-speed traffic—no lorries to hold

up the procession, no delivery wagons to be demolished. Segregating the fast and slow traffic in lanes is not sufficient, as has been proved abundantly already. The road systems must be separate and connected only at wide intervals. The express highways should be guarded by continuous fences, as railways are. There must be practically no grade crossings, no driveways and only a few carefully designed service stations.

This is the price which we shall have to pay if we want to use the top speed of modern motor-cars. Whether we want to pay it depends upon social and economic factors, not upon technology. Such roads can be built if we decide to raise the money.

But even if we do choose to build these express highways, they will have a comparatively small effect upon our mode of life. At most they will increase the practical long-distance touring speed from 50 to perhaps 80 miles an hour. They will save little time except on long trips. They will enable buses to compete with passenger trains in speed as well as in cost, and they will be a boon to holiday-makers. They may improve traffic conditions on ordinary highways by attracting the speed maniacs away from thickly settled districts. This is about all. The express highways will not increase greatly the speed of average motor travel, for most driving is done, and always will be done, on roads where excessive speed is impossible—residential streets, business districts, curving country roads which do not carry enough traffic to justify expensive improvement.

A much greater increase in the usefulness of motor vehicles to the average man could be achieved by concentrating upon the problem of making ordinary traffic flow smoothly and safely at moderate speeds—up to 45 miles an hour. This can be done, and is being done, by simple methods of road improvement, by leading more highways around small towns, by cutting more avenues through our poorly designed cities, by keeping

pedestrians, slow-moving lorries, and other nuisances off the motor roads. Such methods will not raise the top speed of motor-cars, but if they double the *average* speed —raise it from the present twenty to forty—they will have more effect than all the express highways we are likely to build.

I have placed lorries after passenger motor-cars because the majority of them are by-products of passenger-car manufacturing. Light lorries use identical engines and other important parts and will therefore benefit from the same prospective improvements in price, economy, and durability. Heavier lorries which are designed and built for their special jobs are in a different category. They are already as economical and durable as is technically possible at present. Only gradual improvements can be achieved.

Trucks are also divided into two broad classes by the transportation jobs which they perform. Light lorries do not compete very seriously with the railways. They deliver small loads, carry the farmer's produce to the nearest market, and in general do things which the railways never hoped to do. If they come down in cost as a result of the " break " in passenger-car prices which I have predicted above, they will become more numerous and will do their job better. But they will not take on any additional jobs.

But heavy lorries are a different matter. They have largely defeated the railways on short hauls and are gradually encroaching upon the long-haul business. If they continue their gains, they will have a profound effect upon the pattern of life in motorized countries—and all countries are going to be motorized sooner or later.

As I have pointed out in a previous section, the chief disadvantages of railways for freight carrying are their inflexibility and the cost of their roadbed and auxiliary apparatus. Their advantage is that a freight train with a small crew can transport a large amount of cargo with

the consumption of comparatively little fuel. The speed at present is low, but can be improved.

Trucks, on the other hand, are extremely flexible. They will pick up their loads at the point of origin and take them very quickly by the most direct route to their destination. But they use more fuel doing so, and they consume more labour.

Already in the U.S.A. lorries have taken many marginal jobs away from the railways. Their speed enables them to handle much of the perishable freight—fish from the eastern seaboard to the Middle West, fruit and vegetables from Florida to the cities of the North. Their flexibility gives them many of the less-than-car-load-lots. As highways improve and allow them to average better speed, they will absorb an even greater proportion of such business. But they are handicapped in carrying ordinary bulk freight by their high labour and fuel costs.

So the chief point of interest in the future of motor lorries is the present tendency towards greater economy and greater size per unit. Fuel consumption will certainly decrease, Diesel engines accounting for a large part of the gain. Lorries are getting bigger and will continue to do so. Every increase in size cuts the labour cost per ton-mile of pay-load.

The limit to the practical size of lorries is not technical but legal. Since they use the highways primarily intended for lighter traffic, many of the states have passed laws which keep their size within definite limits. Some of these laws are certainly justified. Heavy lorries do great damage to road surfaces not designed to carry them, and long trains of trailers cause excessive congestion because they are difficult to pass. But in many cases the laws are unnecessarily severe and were forced through the legislatures by political pressure of the railways, which fear heavy trucks more than any other form of competition.

Such legal sabotage never continues very long in effect.

The building of express highways limited to fast light traffic will reduce the importance of the congestion argument. Larger tyres and more of them on the lorries will reduce the damage they do to the roads. So we shall probably see much bigger lorries on the highways in the near future. This will put additional problems up to the managements of the railways and will certainly damage the prospects of the widows and orphans who are supposed to depend upon the yield of railway securities. But if the lorries can pay enough taxes to cover the damage they do to the highways, they should not be legislated off the roads no matter what may happen to the money invested in obsolete railway facilities.

With bigger and faster lorries will come bigger and faster buses. They will be dangerous, but the technical knowledge of how to construct them is at hand, and they will certainly carry passengers far more cheaply than they do at present. Most of them will probably be streamlined after a fashion. Every section of the public seems to enjoy riding in vehicles which look like aeroplanes. Even lorries will take to flowing lines, but only when their functions involve a public reaction. Petrol lorries are being streamlined already. They are advertisements constantly in the eye of petrol buyers. Lorries which distribute other highly advertised products will follow. But it will be a long time before we see streamlines on lorries which carry goods of no direct interest to the public.

I am going to end this chapter with a brief review of the prospective improvements in highway transportation.

First, and by far the most important, comes the possibility that the motor-car makers may shake themselves free from the involved commercial tangle which prevents them from rendering full service to society. Their factories are the prize exhibit of mass-production methods. Their engineers are able, progressive and alive. Their

research laboratories are lavishly equipped and supported. But by the time their finished product gets to the consuming public, it has accumulated an excessive amount of unnecessary, non-technical cost which places it beyond the reach of the majority of potential buyers throughout the world.

Selling costs amount to an average of 50 per cent of the list price. This includes advertising, dealers' commissions, and miscellaneous promotion. The cars themselves are much more elaborate than the public would demand if it had not been hypnotized by advertising emphasis upon excess speed, acceleration, smoothness, etc. The yearly models are another source of unjustified expense. Their purpose is to " obsolete " the cars already on the market and force their replacement. One of the largest elements of cost in a new car is that of the dies and other equipment which the manufacturer has to purchase in order to obtain this annual change of superficial appearance.

There are " good business reasons " for all these commercial parasites which have fastened themselves upon the motor-car industry, but there are no technical reasons whatever. A " new deal " in motor-cars would remove most of them and make it possible to sell a serviceable, durable, and economical car for around £40. It would not be as large, as powerful, or as luxurious as present-day motor-cars, but only constant advertising makes the public want these features. What it really wants is transportation. A luxurious, 60-horse-power sedan standing in the rain outside a tenant farmer's drab shanty is a striking proof of the harmful effect which commercial propaganda can have upon the public's buying habits. The farmer needs the car. He should have it. But there is no good reason why he should have to pay for 60-horse-power and opera-house upholstery.

When cars are cut to fit their ordinary uses, the motorization of the world will speed up tremendously.

Even the poorest will be able to buy a car and pay for its fuel and upkeep. Backward countries will feel the effect very strongly. In most of the world to-day only the wealthy can afford any car at all. There is a huge new market waiting, both at home and abroad, for the motor-car business to put its commercial house in order and release to society the benefits of its mass-production achievements.

The second most important prospective improvement will come about when the designers have been freed from the restrictions placed upon them by the public's idea of what a motor-car " ought to look like ". If they were told to design an efficient transportation machine, they would produce a vehicle very different from present-day motor-cars and vastly more efficient. The popular craze for streamlines may make this reform possible. If so, we shall have to be grateful to streamlining, although in itself it will be a very minor improvement.

Cheap aluminium will be another great boon to the motor-car industry. The weight of the car determines largely the power which the engine must possess and the amount of fuel which it will consume per mile. If aluminium becomes inexpensive enough to cut 30 or 40 per cent from the weight of a standard motor-car, a much smaller engine will do the job. The price of aluminium is fixed at present by an effective monopoly, so it is anyone's guess when we shall have the light metal at reasonable cost.

An increase in practical driving speeds depends entirely upon the construction of suitable highways. We know how to build such roads, but the cost goes up much faster than the speed for which they are designed. We shall probably build a certain number of express highways for fast traffic, but much more important results will be achieved by clearing obstructions from ordinary highways. At present, motor traffic averages less than 20 miles an hour. By making the proper changes this

rate can be doubled without allowing any of the traffic to move at excessive and dangerous speed.

Light lorries will become cheaper and more useful with the " new deal " in passenger cars. Heavy lorries are improving rapidly at present, but are kept from their full usefulness by legal restrictions upon their size. When the laws are repealed, the lorries will carry certain important classes of freight much more reasonably than the railways can.

The combined effect upon society of all the advances listed above would certainly be very great. A motor-car industry supplying cheap cars for the masses of China and India would require more machines, mines, factories and skilled labour than exist in America to-day. Faster domestic transportation, made possible by better highways and larger, more efficient lorries, would facilitate this development and allow it to take place without the social penalties of overcrowded cities with all the evils they bring in their train.

It is impossible to say when—or even if—these improvements will be realized. The necessary machines and industrial methods have been devised. The engineers are ready with their blueprints. The metallographers are ready with their alloys and heat treatments. There is plenty of fuel for the engines. All the raw materials are at hand in great abundance. But the non-technical leaders of society are too busy preparing for wars, constructing tariff barriers, and guarding their threatened personal positions to make the proper adjustments. We may have to wait a long time.

AIR TRANSPORTATION

Aviation at present is a very minor factor in transportation. Aeroplanes carry a small percentage of the long-distance first-class mail. They have taken a small percentage of passenger business away from the railways,

They perform a few odd jobs such as making surveys and spraying crops. They carry scientists on certain errands. They provide popular " copy " for the newspapers and are subsidized for the purpose. A few persons use them as expensive instruments of self-glorification—as they used racing motor-cars when these were new.

But that about completes the list. Most of the aeroplanes in operation to-day are military or semi-military. They are supported by governments for the sake of the destruction they are expected to accomplish in time of war. Almost all the " commercial " planes of Europe are in this class, as well as many in the United States.

Nevertheless, the public is right in thinking that air transportation is going to be an important factor in the future. Aircraft have one tremendous advantage over all other vehicles. They are independent of the resistances of the earth's surface. This, of course, is a truism—not news to anyone—but let us see how it relates aircraft to other means of transportation.

Speed is the essence of transportation. Speed is achieved by overcoming resistances of various kinds, but since these resistances all increase much faster than the speed, there comes a point when further increase is practically impossible or undesirable.

We have seen how ocean transportation has already reached this point, and why ships, owing to the rate at which resistance outstrips speed, will never become appreciably faster—not more than a few knots at most. And we have also seen why, although the theoretical top speed of land transportation is very high, the cost of the surfaces—rails or pavements—is so great that the practical speed of land vehicles must remain far below their ultimate theoretical speed.

Aircraft, however, are not subject to this limitation. As soon as a plane is in the air, surface friction falls to zero, giving the effect of an ideally smooth road extending indefinitely in all directions. The only hindrance

to speed is the fluid resistance of the air, which is easily overcome at speeds far greater than any surface vehicles can maintain in ordinary service. This freedom is not acquired without penalties, but it gives to aircraft two simultaneous advantages whose combined effect is overwhelming. No roads need be prepared for their passage. They can go anywhere over land or water. And since they have only the small resistance of the air to contend with, their ultimate speed limit is extremely high. We have not encountered it yet.

THE DISADVANTAGES OF AIR TRANSPORTATION

Practically all the fundamental disadvantages of travel through the air have their origin in one single fact—that aircraft, unlike other vehicles, are supported by dynamic rather than static forces. They are held out of contact with the ground by the reaction of the air propelled downwards by the motion of their wings or other supporting surfaces. The power to move this air must come from the engine. So while other vehicles expend power only to overcome friction and fluid resistance, aircraft have an additional debt to pay. They must also spend power to remain in the air at all.

It is not possible to say in terms of horse-power per pound exactly what this power-cost amounts to. It varies with speed and design, with the density of the air and the loading of the plane. But in all cases it is rather large. In the U.S.A. the newest Douglas transports, very efficient machines, expend 160 horse-power per gross ton when they are moving at their top speed of 217 miles per hour. Of this about 14·5 horse-power per ton is needed to keep them in the air. The rest is available for overcoming head-resistance.

Thus aeroplanes start with a red-ink balance against them, like a farmer who undertakes to make a living

from mortgaged land. Other vehicles can economize on power by moving very slowly. A small tugboat can tow a tremendous string of coal barges at 3 knots. A freight locomotive can pull a mile of cars at 10 miles an hour. They encounter only slight resistance at low speeds. But an aeroplane has not this resource. The Douglas transport must develop at least 44 horse-power per ton at minimum take-off speed or it remains on the ground, a very awkward type of motor-car. Only when it has paid this initial power-debt can it invest additional power in overcoming head resistance and attaining speed.

Of course in the case of aero*planes*—as opposed to autogiros—the supporting force is generated as a by-product of the forward speed itself. But this should not obscure the fact of its existence. No matter how the "ship" is designed, a definite amount of power must be expended for each pound of gross weight supported in the air.

This principle accounts for the late arrival of aeroplanes and for the quickness with which they developed once they had appeared. The basic theory of flying was understood long before the Wright brothers branched off from their bicycle repairing business, but no existing engine was light enough and strong enough to supply the initial "down-payment" of power. Other vehicles spent their infant years on their hands and knees, barely crawling. But the aeroplane had to have muscles strong enough to allow it to leap from its crib into a hundred-yard dash without the benefit of a single practice step.

Now I am going to list the different troubles which are caused by the fact that aircraft must expend power to support themselves and their burdens in the air. The first and most obvious is the high power-cost of carrying weights. This means that aeroplanes will never compete with other bulk-freight carriers except under very unusual circumstances.

A second disadvantage is the serious penalty which must be paid for engine failure. When the engines of earth-bound vehicles stop because of breakdown or fuel exhaustion, nothing very alarming happens. Since the only function of its engine is to maintain speed, a ship can anchor or "lie to". A motor-car or a railway train can wait where it is for repairs to be completed or fuel secured. But an aeroplane sinks to earth shortly after its engine dies. This means that aeroplane engines must be very well built, must be inspected often, must carry a reserve of fuel and oil. All of which add to the cost of transportation by air.

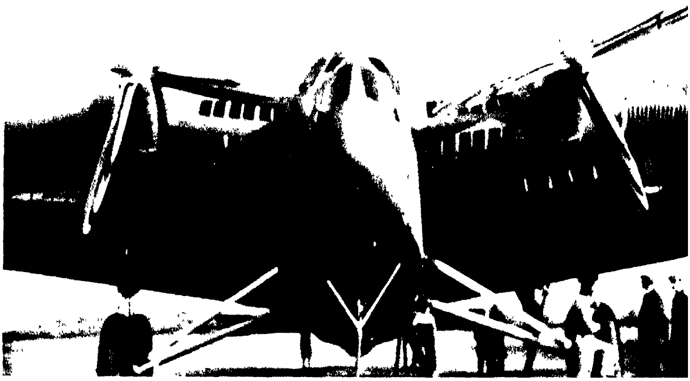
The third disadvantage is the difficulty of coping with adverse weather conditions. When an aeroplane gets lost in a fog or a snow-storm, it cannot wait for conditions to improve. It must keep its engine running or land blindly, a very dangerous procedure. This means that aircraft must either be very particular about weather or carry expensive, intricate, and delicate wireless equipment to guide them safely to port when the visibility becomes poor. The first expedient limits their usefulness. The second adds greatly to their cost and difficulty of operation.

These three disadvantages are the fundamental "outs" about air transportation. Other problems have been largely overcome already. Aeroplanes have acquired sufficient fuel-carrying capacity to cover great distances without landing. They can cross any of the oceans and arrive with plenty of petrol in the tanks. With the aid of suitable wireless they can navigate as accurately as ships. Their cabins are comfortable and quiet. They are no longer dangerous under normal conditions.

But they must still pay high in power-expenditure for the weight they carry. They must still pay high in first cost for dependability. And they are still very much hampered by bad weather. These are the penalties which they must pay for their fundamental advantage,

By courtesy of "Aviation" Magazine

ROTOR HUB OF AUTOGIRO WITH BLADES FOLDED. THE STARTING POWER IS APPLIED THROUGH THE SHAFT ON THE LEFT



By courtesy of "Aviation" Magazin

JUNKERS G-38 WITH ENGINES AND PART OF CABIN SPACE INCLUDED IN THE WING

freedom from the resistance and irregularities of the earth's surface.

The future progress of aviation will depend on the balance between these disadvantages and the advantages of high speed and low-cost right-of-way. The balance is constantly shifting in favour of aircraft. In the next section I shall explain how the negative factors have been reduced recently and how the favourable factors have been increased. We are not yet in sight of the limit to this process.

RECENT IMPROVEMENTS IN AIR TRANSPORTATION

First comes the minimum power expenditure per pound of "gross load". It is doubtful if this figure itself has been reduced very greatly, but there are other ways of attacking the problem. Aircraft are not useful in proportion to the weight they can lift off the ground, but to the pay-load they can carry from point to point and to the speed with which they can do it. Thus the power expenditure "per-ton-mile-per-hour" of useful load is the vital figure.

This is being rapidly reduced in various ways. Aeroplanes are becoming much lighter in proportion to the load they will carry and their speeds are increasing. Ten years ago a transport was considered very good if it would carry 50 per cent of its own weight at a cruising speed of 100 miles per hour. The latest transports will lift almost 100 per cent of their weight and carry it at 200 miles per hour with approximately the same engine power, which represents a tremendous gain in "power per-ton-mile-per-hour".

This was not accomplished by any striking single invention, but by a large number of simultaneous improvements. The engines decreased in weight per horsepower from 2·5 pounds to 1·5 pounds. Better structural

methods and stronger light alloys reduced the weight of the wings and fuselage. Better streamlining reduced the "parasite resistance"—the portion of the power requirement which does not contribute to keeping the plane in the air.

The second unfavourable factor, the possibility of engine failure, has been almost eliminated. Ten years ago an engine on an air line was good if it would operate 150 hours without complete overhaul. Modern transport engines need overhauling only after 500 hours.

Much has also been done to reduce the weather handicap. The increased load capacity allows aeroplanes to carry plenty of fuel. Therefore they can circle longer above a fog-bound airport or can proceed to another where conditions are better. Their greater speed enables them to fly around many storms. Their higher "ceilings" enable them to fly over some more. Modern meteorology can predict weather conditions fairly accurately and pass its findings by wireless to the planes in flight. Modern wireless can guide the planes to port and help them land in fog or snow. Aircraft are still greatly hampered by bad weather, but much less so than in the past.

So much for the reduction of disadvantages. The balance has also been tilted by increasing the advantages. The first fundamental advantage, speed, has increased very greatly. Five years ago the air lines averaged 110 miles per hour. Now the fastest transcontinental planes average almost 200 miles. At the lower figure the aeroplanes had only a slight edge on the trains. Now they have outdistanced them completely.

Aeroplanes could always "go anywhere" in theory without requiring a prepared road, but in practice there used to be serious qualifications. They dared not fly at night for fear of getting lost. Now they can and do, thanks to the Department of Commerce with its beacons and wireless. They could not make long "water

hops " without paying too great a penalty in hazard and the amount of non-paying fuel which had to be carried. Now they cross the Caribbean regularly and will be crossing the North Atlantic and Pacific in a few years on commercial schedules. Formerly they could land only in the comparatively few cities and towns which possessed suitable airports. Now most cities have good flying fields, and the planes have been so improved that they can land and take off in many places which would have been considered prohibitively dangerous a few years ago.

These improvements have tipped the balance just enough so that a few aircraft can operate without depending either upon government support or novelty interest. Not many, of course. Military planes don't count. Neither do mail planes nor the subsidized passenger carriers of Europe. Nor do exhibition or racing planes or " joy hoppers ". But there are a few aircraft which do genuine work unsupported by these artificial sources of revenue. A few scattered air lines are earning money. Aeroplanes are profitable in Alaska, China, Latin America, and the mining regions of northern Canada—all of which are places where railways and highways are few.

Probably even if aircraft should not improve beyond the point they have reached at present, they would multiply greatly as the result of increasing popular interest and the working out of operating problems. But the balance is tipping in their favour more and more all the time. In the next section I shall point out the chief ways in which they are likely to improve in the near future.

THE FUTURE OF AIR TRANSPORTATION

It is impossible to discuss aircraft in one lump, as if they were locomotives or passenger motor-cars. There

are too many different types, performing different functions, governed by different economic laws, and satisfying different human wants. Aircraft are going to compete in some degree with all other types of transportation, from ocean liners to the family flivver. They will be constructed by different methods and will take radically different forms.

Neglecting military planes as outside the scope of this book, I am going to group aircraft in two broad categories. First will come those designed for private, individual ownership. They are roughly equivalent to passenger motor-cars and light trucks. There are only a few thousand of them in existence at present, but we have good reason to hope that they will become very numerous in the future.

The second group will include all " common carriers " of the air, roughly equivalent to ocean liners, railway trains, and buses. This type dominates the non-military field at present, as its equivalent in land transportation did before large-scale mass production made private motor-cars cheap and numerous.

Two factors are holding up the development of private flying at present: the high cost and the difficulty of safe operation. First I shall take up cost. To-day the cheapest light plane which is even moderately dependable costs £300, far too much for the average man.

Back in the nineteen hundreds, before Henry Ford got into his stride, motor-cars were selling for around 3,000 dollars. This was chiefly because they were made in small quantities. Only some 43,000 were produced in 1907, and there were more manufacturers in the business than there are now. They could not afford to buy or operate even the primitive mass-production machines which were available at the time. So their motor-cars were built " by hand " and were consequently very expensive.

This is the situation in the aircraft business to-day.

During the first nine months of 1934 only 673 non-military planes were built for use in the United States. This includes every type from the largest flying boats to the smallest personal planes. Obviously they were all built " by hand ". Numerous machines were used in the process, of course, but most of them were only improved tools such as riveters and welding devices. They all stood idle most of the time and consumed a great deal of labour while in use. If the modern Ford V-8 were to be made by similar methods it would cost perhaps £1,000 instead of £100.

The great hope for the future is that this situation will not continue for ever. If light aeroplanes were made in sufficient numbers to benefit from mass-production methods, there is no reason why they should cost more than popular priced motor-cars. There is even a good chance that they might cost less.

A light aeroplane is actually a much simpler machine than a motor-car. It has no transmission, clutch, universal joint, drive shaft, differential or axles. It has only two small, inexpensive, wheels with thin-walled tyres and rudimentary brakes. The springs are represented by rubber cords which should cost practically nothing. The fuselage is certainly not more elaborate than the body of a motor-car, and the engine need be no more powerful than those which are supplied with small cars to-day. Controls are roughly equivalent on both vehicles, and so are lights, starters and petrol tanks. The only items of cost peculiar to aeroplanes are the wings and tail surfaces, the propeller and certain instruments.

Engines are by far the most important expense in aeroplanes at present. There is a popular impression that aeroplane engines have to have certain mysterious qualities which make them inherently more costly than motor-car engines. This is not the case. They have to be well built, light, and dependable, but a good motor-

car engine—the Ford V-8 for instance—reaches this standard to-day. It is not suitable for use in an aeroplane for various reasons, but if the Ford company were to turn its attention to making aeroplane engines in large quantities, it would turn out excellent jobs without much change of method. They would cost no more than the engines which go into the cars to-day—well under £20.

Several motor-car manufacturers, indeed, have announced that they would be eager to supply 75-horsepower aeroplane engines in lots of 10,000 for not over £20 each. This is not charity or patriotism. There would be a good margin of profit in the enterprise. The engine represents at least one-third of the price of the present-day light plane. So this single item if made in large quantities would cut at least £80 from the cost of the cheapest plane available to-day.

The next largest expense in building light aeroplanes is for the wings and tail surfaces. These are all assembled by hand from numerous small parts. There is no technical reason whatever why they should not consist of a few parts stamped or forged by large automatic machines. Nothing prevents it except the small scale of operations, which will not pay for such equipment.

At present most transports carry an appalling array of expensive instruments. Many of them would not be needed in small private planes, and those which remained would not cost very much. Their delicate parts are well adapted to manufacture by mass-production methods. Fine production machines, when adjusted properly, will turn out extremely accurate parts at very small expense. The price of good watches is excellent proof of this.

Propellers are another item which need not cost much. They are merely simple pieces of metal with accurate shapes. Production of such things is child's play for automatic forging or grinding machines. They can do

it more easily than anything else. Propellers could be made without using any hand labour whatever.

This concludes the list of aeroplane parts which do not cancel out against similar parts on motor-cars. And it leaves a large balance in favour of the aeroplane: the running gear, transmission, brakes, springs, etc., which aeroplane manufacturers need not worry about at all.

One source of expense I have not mentioned yet, the light alloys which form a large part of an aeroplane's structure. These cost at present about 1*s.* 8*d.* or more a pound, and a light plane usually contains a considerable amount of them. But as I have stated in an earlier chapter, there is an excellent chance that the price of aluminium and magnesium will fall very greatly within a few years. It is being supported only by financial forces which will have to yield ground sooner or later.

The foregoing is a very brief survey of the price problem of the cheap plane. Considering all sides, we can conclude that the Department of Commerce set the price limit rather high when it asked for a popular plane at £140. Mass production, even allowing for all sorts of "selling costs", can surely do better than that.

There remains the problem of finding a market. No commercial interest will undertake the mass production of aeroplanes until it sees a good chance of selling at least 50,000 units a year after a reasonable period of time. Needless to say, there is no such market in sight at present. Last year the Department of Commerce asked 18,000 pilots, student fliers, and mechanics whether they would buy a two-seated plane with certain properties for £140. More than half replied that they would.

This was a well-meant piece of propaganda, but it misled no one. The questionees were either aviation enthusiasts or directly connected with the industry in some capacity. They all understood that the purpose of the questionnaire was to stimulate aviation. The

wonder is that they did not all answer in the affirmative. If the question had been sent to the general public and had included some question to determine sincerity, there would have been an overwhelming chorus of thundering " No's ". Very few average men have any use for a present-day aeroplane at any price. They are too dangerous, too difficult to operate, and they perform no useful service.

When aeroplane manufacturers try to cheer one another in the columns of their trade magazines, they talk of " sport flying ". But they all know very well that flying a plane is a rather poor sport, not a sport at all in fact. It cannot contain the essential element of competition without becoming far too dangerous, difficult, and expensive. After the first few experiences, " joy flying " becomes dull. To untrained eyes the earth with its people and scenery is much more interesting from the ground. The only conceivable buyers of non-useful sport planes are exhibitionists like those who bought " mile-a-minute " cars when the motor-car industry was young and raced them over country roads defeathering chickens and getting their pictures in the papers. This class will never support a large-scale industry, for such men desert at once as soon as the novelty wears off and the publicity begins to come hard.

Aircraft must become not only inexpensive, but comparatively safe and easy to operate, before the public will buy them. They must take at least the man of slightly-above-average means to the places he wants to go and bring him back without discomfort or hazard. At present they meet none of these requirements. They need large airports, which are seldom near the homes of the prospective buyers and almost never near their offices. This cuts out commuting by air. If fog or snow is encountered, they become very dangerous playthings, for they can neither fly blind like wireless-guided air liners nor " park " and wait until things clear up.

They must try to land as best they can. Few non-professionals are willing to take their chances under these conditions with power-lines, trees, fences and other unseen obstructions. Furthermore, learning to fly a present-day plane requires much more time and effort than the average man is able or willing to expend.

Most of these difficulties would be eliminated at one blow by a type of aircraft which could take off and land at zero forward speed. It would not need a large airport. City roofs or co-operative backyards in suburban districts would serve the purpose. A large proportion of accidents occur to-day at the moment when contact is made or broken with the ground at high speed. These would be avoided. The weather hazard would be reduced almost to nothing by aircraft which could float down vertically out of the fog.

By far the most promising development in this direction is the autogiro. It has one fundamental advantage. In aero*planes* the lift is a by-product of the forward speed. No speed, no lift. Therefore they cannot rise from the ground without making a long horizontal run. Similarly they must make contact with the ground at high speed. A skilful pilot can "pan-cake" a conventional plane so that it hits the earth without much forward velocity, but this is not a procedure to be recommended to the general public. It will always be far too dangerous.

Autogiros are built on an entirely different principle. When they are in flight, their lift has nothing to do with the forward speed. The "windmill" which supports them is kept spinning by the backwash from the propeller. If the engine stops for some reason, the windmill still spins, and the ship floats gently and vertically to the earth. This property may seem rather uncanny, but the same thing happens when a maple seed drops from the tree. Thistle seeds are parachutes, but maple seeds are one-blade autogiros without engines.

So autogiros have solved half of the problem already. They can land vertically and gently even with their engines dead. But they have not yet solved the other half. When an autogiro wishes to rise from the ground, it has to start its windmill spinning by means of a power take-off connected with the engine. When the blades are moving fast enough—but never with sufficient speed to lift the machine by itself—the take-off is disconnected and the power applied to the forward propeller. The ship then rises at a flat angle like a conventional plane. It rises rather quickly, but by no means vertically.

This may not always be the case. The leading manufacturer of autogiros is working on an idea which may solve the other half of the problem, the vertical take-off. The roto-blades of an autogiro are shaped like narrow wings and are set at a slight angle to the horizontal. It is this angle which gives them their lift. If spun at sufficient speed by the engine they might gradually acquire enough lift to raise the ship from the ground a few feet. This is not desirable for various reasons, chiefly the difficulty of control.

But what the autogiro designers propose to do is make the pitch of the blades variable. When the ship is on the ground preparing to rise, they would be set so that they would have no lift at all. This would reduce their drag and allow them to be spun by the engine at very high speed. Then the engine would be disconnected. The blades would be reset to a lifting angle. And the power stored up in their rapid motion would lift the ship rapidly and vertically to a height of some hundred feet. Then the forward propeller would come into action, and the ship would fly off horizontally, like a bird leaping high into the air before unfolding its wings.

The mechanical details of this startling improvement have not been worked out as yet. The hub of an autogiro's windmill is complicated already. It will be difficult to add the controllable pitch. But it is certainly

not impossible. There is no definite physical limit which forbids it.

Vertical-rising autogiros have not been tested yet. But we already have autogiros with very promising abilities. One by one they have eliminated or overcome their early failings. At first they were very poor weight carriers. To lift 1,000 pounds of useful load, 300 horse-power was needed. The latest model Pitcairns can carry a load equal to their own weight (600 pounds) with only 75 horse-power. At first they were very slow. They are not designed for high speed even yet, but now moderately powered models can fly at 125 miles per hour—fast enough for private use. They have another safety feature beside their ability to land vertically. They cannot "spin" or "stall". They will not do all the stunts of which aeroplanes are capable, but a little less stunting would be a boon to aviation. It causes a large number of the unnecessary accidents.

On the whole, autogiros look as if they might solve the problem of the "personal" plane. They are too new to be considered perfected. The wingless type, controlled by tilting the rotor column, was brought out only in the fall of 1934. It is still full of "bugs" and crudities. It is manufactured in extremely small numbers and so is very expensive, but there is no reason why it should cost more than a light aeroplane once it gets into quantity production.

Conventional light aircraft also are improving rapidly in respect to safety. Their landing run and the difficulties of operating them are being substantially reduced. Their petrol consumption is falling. A small two-seater will fly 90 miles in an hour on only 4 gallons. This is better than most motor-cars will do, even leaving the speed out of consideration.

But however good aeroplanes become they will always require more room for landing than the autogiro. They will never be able to float gently to earth like maple

seeds. It would be too much to say that the future of private flying lies entirely with the autogiro. Too many things can happen in a field as unexplored as aviation. But we can say that at present the autogiro comes closest to filling the requirements. It is comparatively safe. It is easy to operate. It will land in a restricted space. It may learn to take off vertically. And there is no reason why it should not be built very cheaply.

If private aircraft do come into general use, they will bring about changes at least as far-reaching as those caused by the motor-car. Their most important effect will probably be to spread centres of population much more widely over the surrounding country. Even backyard flying fields require large backyards. So necessity will come to the aid of natural preferences in causing people to leave congested areas. Commutation by aircraft will never become as dependable as by train or motor-car, but this disadvantage will be discounted once aircraft become firmly established in the public mind. If the boss is subject to delay by fog and low " ceilings ", he will not be too harsh with his employees.

Another effect will be to allow the temporarily unattached to flash around the country like quicksilver. The week-end radius will be enormously extended. It is very unlikely that personal planes will ever cross the oceans regularly, but they will certainly penetrate to all land areas which can be reached without excessively long water hops.

Of course the death toll of this development will be tremendous. Aircraft can be made comparatively safe, but they will never become fool-proof. And our experience with motor-cars has proved that fools are plentiful. No matter how aircraft are designed, there will always be reckless youths to try to fly under power lines, to play tag in the air, to show off to their girl friends. There will always be careless owners who fail to keep

their engines and controls in repair. There will always be plenty of men and women who want to see what the inside of a thundercloud looks like. Aircraft are inherently more dangerous than motor-cars, even with the hazards of collision largely removed.

But all during the history of modern civilization we have become more and more careless about mechanical risks. This is one of the prices we pay for speed and the use of power machinery. Perhaps it is nature's evolutionary method of improving the race by weeding out young those individuals who are psychologically unfit for the life of the future. The motorist who habitually passes fast buses on blind curves is likely to be prevented by sudden death from having children who will try to land their aircraft without making sure which way the wind is blowing.

At any rate highway fatalities have not slowed the development of motor-cars to any noticeable extent. No death-rate due to preventable accidents will hamper private flying. It is only the feeling that he may be killed by factors entirely beyond his control which makes the average man hesitate to trust his life to aircraft. When this fear is removed, by technical improvements and by propaganda, the public will take to the air without worrying about what happens to the reckless and the foolish.

COMMON CARRIERS OF THE AIR

In the above section on private flying I have considered only three factors: cost, safety, and practical usefulness. These dominate the situation. Top speed is secondary. Private aircraft may become very fast, but already the slowest modern planes are amply fast enough to become attractive to the public as soon as the other problems are solved. They can fly from point to point in about one-third of the time it takes a motor-

car to cover the same distance under prevailing road conditions. This is decisive. No more speed is necessary.

The same is true of range and weight-carrying capacity. Small, standard planes will carry enough useful load to allow them to transport two passengers with a reasonable amount of baggage at least 350 miles. This is plenty. After private planes become common, there will be no real need for long non-stop flights. The civilized world will be dotted with airport filling stations.

But when we consider commercial aircraft designed for carrying pay-loads long distances, we find the conditions radically different. Speed, range, and load capacity take first place. Purchase cost and safety are still important, but they do not dominate the situation as in private flying. A commercial plane constantly in use can afford to be much more expensive to buy than an air flivver which stays in its hangar most of the time. Safety is necessary, but it can be obtained by means of instruments, wireless guidance, and pilot skill. Air liners do not have to be designed so that the general public can operate them safely.

Speed is the air lines' stock-in-trade. On some routes they have the additional advantage of cutting off long detours, but this is the exception rather than the rule. Most air lines compete with passenger trains, and the wider the margin of speed in their favour, the more business they can attract and the higher the rates they can charge. High speed reduces some of their costs as well. Pilots and planes cover more paying mileage in a day, which means less in wages, depreciation, and interest per fare collected.

There are various reasons to believe that the future will bring us much faster planes than we have to-day. Take the matter of "streamlining", that magic word so much misused by people with products to sell to the public. Streamlining is the art of shaping a large object so that it will move through the air as if it were a small

one. The ideal shape changes with the speed, but a proper egg-shaped body with a sharp tail may meet as little as *one-fortieth* of the resistance which a disc of the same frontal area would have to overcome. Therefore the chief job of aeroplane designers is to make their ships approach as closely as possible the ideal egg-like shape.

.This is hard to accomplish, for other requirements have to be met as well. There must be wings and tail surfaces, all of which are more or less flat. There must be wheels or pontoons, lights, shock absorbers, and usually various struts and braces. Finally there must be a place to stow away the engines, the fuel, the passengers and the crew.

The problem of the designers is to mould these stubborn elements into a low-resistance shape. Taken in order of importance, the wings come first. To stay in the air a plane must have lifting surfaces. The other elements are necessary, but theoretically they do not need to be exposed to the air-stream. The only exceptions are the propeller and the control surfaces. The propeller does not offer direct resistance to forward speed. It produces thrust, not drag. And the control surfaces are not important in this respect.

So externally the ideal plane would be merely a wing with sufficient lift. The other elements with the exception of the propeller and control surfaces would all be stowed away inside, out of contact with the air stream and therefore offering no resistance to forward motion. The only *volume* which demands to be dragged through the air is the space occupied by the thickness of the wing, a by-product of the necessary lift. If everything else could be packed into this space, an ideal plane would result.

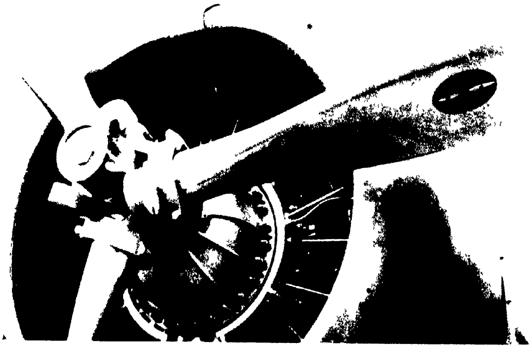
Naturally this can't be done at present, but the designers are approaching the ideal with considerable rapidity. A few years ago many planes raked the air with a large

number of assorted struts and braces. These have largely retired into the wings. Landing wheels stuck out into the air-stream. Now they can be drawn back into the fuselage or the wings when the plane is in flight. Radiators and control wires have disappeared from sight.

The most interesting result of this advantage of " cleaning up " is the stimulus it has given to the construction of very large planes. About five years ago the common opinion was that large planes would never prove efficient because of the so-called " square-cube " rule. The reasoning went something as follows: The weight which a wing will support is proportional to its area. Each square foot, let us say, will support ten pounds. A wing with an area of 200 square feet will carry 2,000 gross pounds. If we multiply the linear dimensions of the wing by two, its area will increase as the square of two, or four times. It will then have an area of 800 square feet and will support 8,000 gross pounds.

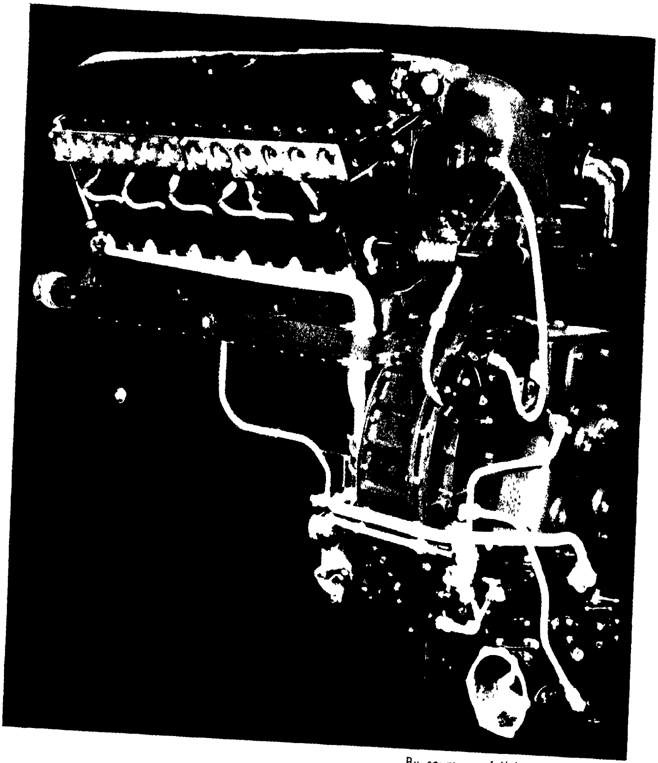
So far so good. But if all the other dimensions of the plane are also multiplied by two, the volume of metal and therefore the weight will increase not as the square but as the *cube*. If the smaller plane weighed 1,000 pounds empty, the larger plane would have to weigh 8,000 pounds empty. And the larger wing would support only 8,000 pounds, leaving no margin for useful load, while the smaller plane would carry 1,000 pounds of it. This was given as a definite reason why large planes would never prove efficient, and it was backed up by the common observation that gnats and mosquitoes keep in the air more easily than crows. All flying things are subject to the square-cube rule.

This was perfectly good reasoning as far as it went. but it failed to take all the factors into consideration. Large planes have two advantages which have enabled them so far to postpone the application of the square-



By courtesy of "Aviation" Magazine

CONTROLLABLE-PITCH PROPELLER FOR HIGH ALTITUDES



By courtesy of "Aviation" Magazine

ENGINE WITH MECHANICALLY DRIvEN SUPERCHARGER (WITHIN DRUM AT LOWER RIGHT)

cube rule. In the first place the designer of a large plane has much more freedom to stow engines and other bulky parts away inside where they will not cause drag. In the largest modern planes they are " faired into " the wing itself, the ideal place for them. All commercial passenger planes must have cabins with sufficient head-room for the passengers. No more is needed in larger planes. The passengers may increase in numbers, but they do not become taller. This results in a very considerable saving, both in weight and " parasite drag ".

Even more important is the weight saved by structural methods which are practical only in large planes. Thick wings are structurally stronger than thin ones. Therefore less metal need be used in proportion to size. This is also true of all other parts which are subject to bending. The duralumin sheet which covers the wings and the fuselage does not need to be made much heavier. The instruments, lights, controls, safety apparatus, etc., do not increase in weight. Neither do the pilots or the " hostess ".

So the absolute limit to the size of planes has receded far into the future. They are sure to become much bigger—especially flying boats, which do not have to worry about the size of landing fields. Perhaps sometime they will become big enough so that not only their engines but their passengers themselves may be stowed away inside the wing. This will make them very efficient. Practical difficulties may prevent it, but they have not appeared on the horizon as yet.

Besides better streamlining made possible by larger size, commercial planes have still another opportunity to attain higher practical speeds. The resistance of the air is proportional to its density. Air which is half as dense as at sea level offers only half the resistance. Therefore a plane can fly through it twice as fast without expending more power. The extreme form of this is

the so-called " stratosphere flying " so popular with the inspirational press.

It has been known for many years that planes could theoretically fly faster at high altitudes, but until recently practical obstacles have prevented them from doing so. In the first place petrol engines, like human beings, breathe air. The power produced is proportional to the amount of petrol burned. If the air entering the engine is thin, it will burn less petrol and produce less power. So by ascending to high altitudes the planes of yesterday lost in power while they gained in freedom from head resistance.

They lost in another way too. Their propellers had been designed for air of normal density. In thin air they lost their grip, to spin rapidly and inefficiently without pulling the plane forward as they should. The combined effect of these two disadvantages kept the air liners near the ground. But this is the case no longer. Two developments have raised the " ceiling " of top efficiency until it now stands at about 8,000 feet.

The first of these is a fan or rotary air pump to keep the pressure in the cylinders up to normal at high altitudes. These " superchargers " are nothing new. They have long been used on racing motor-cars and certain special types of aeroplane, but they were too inefficient and troublesome for commercial purposes. Recently they have been improved greatly so that an engine equipped with one of them does not lose much power below 10,000 feet.

The difficulty with the propeller has also been overcome. The grip of a propeller on the air is largely dependent upon the " pitch " or angle at which the blades are set. The greater the angle, the more grip. But the angle must not be too large or the propeller will grip the air too much at sea level and will slow the engine down below its most efficient speed.

Obviously the remedy for this dilemma is a propeller with variable pitch. Easier said than done. Literally hundreds of able inventors worked on this problem for many years without solving it. The trouble was dependability. Aircraft designers distrust a propeller which is not one solid piece of metal. If a blade comes off in flight, a complete disaster is almost sure to result.

But the problem was finally solved last year. Now there are several dependable propellers on the market which can be adjusted in flight to fit the density of the air. When the plane is taking off from the ground, the pitch is set low so that the engine may revolve at its most efficient speed. As the plane climbs the pitch is gradually increased. The action is something like the gear shift of a motor-car. The planes leave the ground in low gear, but shift into high as they rise into thin air.

Equipped with these two new devices, the air lines have quietly increased their customary flying altitude to 8,000 feet. They did it quietly so that the public, full of the terrors of the " stratosphere ", would not become alarmed. This move is responsible in part for the great burst of speed which the air lines made last year. They could not possibly maintain their present schedules at ground level.

How high it will prove practical to fly in the future is hard to say. The limiting factor is not the mechanical equipment of the planes, but the altitude the paying public will stand for. This is unknown and can only be tested by gradual experiment. In normal activity on the ground, the atmosphere characteristic of an altitude of 10,000 feet would be apt to be extremely uncomfortable for a person accustomed to sea-level pressure. But in a plane, where no muscular activity is possible, this altitude may be reached before the average passenger notices anything unusual. His muscles are not using much oxygen, so he does not miss his usual supply.

Perhaps it will turn out that passengers will not object to flying as high as 15,000 feet. At this altitude the air has lost nearly half its density. Almost half the resistance is gone. Many clouds and storms are left far below. There is little to be gained by flying higher. An additional climb to 30,000 feet would reduce the resistance only 25 per cent more, and the air would be far too thin to support human life.

It is possible, of course, to fly in the " stratosphere " —that vague region above 40,000 feet. It has been done several times by pilots in search of altitude records. But when artificial air must be supplied to passengers and crew, the practical difficulties become enormous. Oxygen apparatus is heavy and expensive. It is also extremely unpleasant to use. No paying passenger will stand for the discomfort and risk. Attempts have been made to " supercharge " the entire cabin, but they have proved uniformly unsuccessful, even as experiments. To hold the pressure, the cabin has to be built like a tank within the usual streamlined fuselage. The added weight destroys any possible advantages.

In " the next war ", military planes will probably fly far above the life-supporting level. There are numerous tactical advantages, and it is comparatively easy to " supercharge " a small crew. Even mail planes may follow. Letters need no oxygen. But it is very doubtful if passengers will ever be carried at heights where they cannot breathe the natural air. The rewards are too small and the penalties too great.

REMAINING OBSTACLES

Commercial planes have been so vastly improved in the last few years, that it is rather remarkable they have not captured a larger place in the transportation system. The technicians are not to blame for this. They have done their job better than anyone dreamed they could.

The reasons are to be found, as usual, in the fields of economics and politics.

The depression, of course, is the chief reason. The present high cost of air travel is largely due to the small amount of business available. Frequent flights are necessary if the passengers are to save time except on very long routes. There is little advantage in flying from New York to Boston if you have to wait three hours for the plane to start. If a railway train leaves in an hour, it will get you there as quickly.

But under present economic conditions, few air lines have enough business to fill more than a few large, efficient planes a day. If they could fly "every hour on the hour", more people would use them. This is one of the numerous vicious circles of the depression. Few people have money for high-priced air travel. Therefore the air lines are forced to restrict their service. Therefore they become less convenient and more expensive—both of which conditions keep the traffic low.

More traffic would reduce operating costs tremendously. At present an air line has to maintain an elaborate ground organization for the sake of a mere trickle of business. If it could distribute the cost of this among fifty times as many passengers, the rates could be lowered greatly. Even now the air lines do not charge very much more than the railways. A large increase in traffic may allow them to charge actually less. The threat of this is one of the things which gave railway presidents bad dreams and led them to make the brave gesture of the "streamlined" trains.

The future of air travel across the oceans is even brighter. Planes are now available which can cross to Europe by way of Bermuda and the Azores without danger or difficulty. They are at least five times as fast as the speediest ships will ever be. They are not only faster, they are more comfortable. "Airsickness" is nothing to seasickness. It affects only 3 per cent of

the passengers and will decrease as the planes improve. Storms can be flown around or over with ease.

Here is where the political factor stands in the way. The world, as we all know, is in the midst of one of its periodic fits of nationalistic face-making. This childishness has held up numerous other developments, but it has hurt international aviation more than anything else. The air lines to Latin America are running without a hitch, but exchange restrictions caused mainly by tariffs and embargoes have forced many wealthy South Americans to stay at home and have reduced to a fraction the business travel which is incidental to international trade.

The same is true in even greater degree of prospective air travel across the Atlantic. The British government has not yet given full permission for American air lines to use Bermuda as a stopping point, but even with this restriction removed, the available traffic would be comparatively small. Germans and many other central Europeans are not allowed to travel outside their boundaries at all. Their political bad manners keep American visitors away. France and the rest of the "gold bloc" countries are too expensive for most American tourists. In every part of Europe, and the rest of the world for that matter, the myriad regulations of economic warfare have operated to keep business travellers at home.

When this situation clears up, we shall certainly see the air lines come into their own. Even a slight improvement might be sufficient. They have solved all the essential technical problems. All they need now is traffic. When they get enough of it, they will be able to reduce their rates. Then the real expansion will come. Air lines do not need to wait for rails to be laid or roads built. All they need are the planes and the pilots to fly them. As soon as economic and political conditions take a favourable turn, they will grow faster

than any transportation system has ever grown before. This will certainly damage the railways and luxury passenger ships. Perhaps it will even hurt the motor-car industry. But it may prove just what we need to pull us up to the peak of the next period of prosperity.

VII

COMMUNICATION

COMMUNICATION is the transportation of ideas, a process necessary whenever two or more living beings attempt to function with a co-operative purpose. Therefore it is an essential element in the construction and maintenance of civilization. Before individual men—or insects, for that matter—can enjoy the benefits of co-operative action, they must be able to keep in touch with one another so that common ideals, hopes, and desires may be formed and discovered. After these are agreed upon, constant communication is necessary in order to keep each member of the group informed as to the part he is expected to play in the joint enterprise.

Naturally, the more efficient the means of communicating, the better the co-operative action which can be achieved. More individuals and communities come to recognize the purposes they have in common. More orders and suggestions can be exchanged and more quickly. Therefore we can say that the communication system is the framework on which civilization is built. Sometimes we neglect or refuse to use the framework to its full extent, but that's another matter.

Human beings communicate with one another in two general ways. The first is by causing various disturbances in a connecting medium. These include speech carried by compressional waves in the air ; wireless messages carried by disturbances in the " lumeniferous ether " ; and telegraph and telephone messages carried by fluctuating currents in metallic conductors. The second method is to transport records of various kinds :

letters, printed matter, diagrams, and motion-picture films.

It would be possible to write a history of communication in terms of a battle between these two methods. The first is by far the older. Men could talk or make signs long before they looked much like men. The earliest use of the second method was the human courier with a memorized message impressed upon his brain. Then writing was invented and became more useful with the invention of printing until it crept up to comparable importance with speech. The " disturbance " method won no technical victories until the invention of the telegraph. It lost ground subsequently when the railways speeded up the mails, but regained it by means of the telephone. After that, inventions came thick and fast. The phonograph, the typewriter, the cheap newspaper, and the motion-picture fought on the side of the " transported record " method. The wireless fought against it. The latest recruits are the sound movies and the air mail on one side, facsimile transmission and television on the other.

But every improvement, no matter what means it used, had the same general effect. They all enabled more individuals to act in unison. They caused the spread of similar ideals, habits of thought, prejudices, and desires. They reduced the confusion of languages. They allowed tyrants to control more distant provinces or enabled outlying regions to impress their desires upon the central government—opposite tendencies but with the same ultimate effect, better unity within nations and empires.

The most recent and striking result of the efficiency of modern communication is certainly the spread of " propaganda dictatorships "—government by consent of the scientifically misled. Hitler and Stalin, Mussolini and the Japanese militarists have all built their power on the fact that the means of shaping public opinion have become extremely centralized and are therefore

easy to control. They could never have managed to warp the judgment of their subjects so efficiently without almost the whole list of modern communication methods : telegraphic news agencies, popular newspapers, wireless broadcasting, and the movies.

We may not like these curious political structures. (I certainly do not.) But we must admit that they have achieved a degree of practical unity within their borders which would be very useful to the progress of civilization if turned in a constructive direction. With the possible though doubtful exception of Stalin, all the dictators, big and little, have used their new-found powers to foster narrow-minded nationalism, the most implacable enemy of technical civilization. There is great danger that the patriotic lies they have spread by means of modern scientific communication may bear fruit in a series of wars more destructive and agonizing than any we have yet experienced.

But we should not blame improved communication for this, any more than we should blame chemistry for poison gas or naval architecture for the submarine. The nationalistic dictators have merely turned good tools to bad uses. We can cheer ourselves by hoping that some day the tools will fall into less destructive hands.

The change had better come soon, too, for communication is improving rapidly. In the near future it will be able to bring about even more complete national unity, for good or evil. Mussolini's propaganda *tour de force* of turning Caporetto into an Italian victory was effected by reiterated lies in a centrally directed press. Hitler convinced the Germans that he was a " Nordic hero " chiefly by means of wireless broadcasting and voice amplifiers. The dictators of the future, armed with television and other impending improvements, will accomplish even greater things.

But in spite of such misuse the fundamental long-range effect of communication is to make individuals

realize that they have interests in common. All through history we can trace its progressive good work in breaking down hostile boundaries between villages, feudal principalities and neighbouring peoples of similar culture. The warlike nationalism which it has fostered in the last fifteen years may be considered an evil but temporary by-product. It may bring us disastrous wars in the near future, but eventually improved communication will allow nations to work together without military conflict, as villages and cities do to-day.

This is the chief benefit which we may expect from our new methods. In the next chapter I am going to concentrate on those means of communication which promise to accomplish this result—if they are allowed to do so.

AEROPLANE COMMUNICATION

One of the most important recent developments in communication has already been treated under aviation. Every improvement in fast transportation makes more effective every type of " transported record " communication. Air mail has already become sufficiently fast and dependable to take a great deal of business away from certain cable companies, as those with lines to South America will tearfully testify. In the domestic field it has speeded up business and social communication to a lesser extent.

But the full effect will be felt when air transportation becomes really cheap and fast—when air mail costs no more than first-class mail to-day and is flown direct to all towns of moderate size. Metropolitan newspapers, for instance, are sure to use it freely to extend their influence over wider areas of adjacent territory. Possibly the newspaper map of the United States will come to resemble that of England to-day, where practically all important papers are printed in London. Weekly maga-

zines will be able to indulge in more "timeliness", and will so gain more intellectual leadership. Mail-order selling will benefit. So will all other businesses which involve large amounts of long-distance mail.

The net result of these changes is sure to be a greater centralization of the nation's executive and intellectual functions. Many organizations will be able to abandon local branches. The provincial districts will learn to take more of their styles, opinions, and orders from the capital. Those who don't like this prospect should write their Congressmen promptly to abolish the air mail. But those who want modern civilization to continue to develop should rejoice, for it is certain that technical progress is favoured by better unity over larger areas.

Cheap air transportation will also bring regions and nations more harmoniously together by means of that oldest form of long-distance communication—memories impressed upon the minds of travellers. This does not always work, as the present state of mind of Europe will indicate, but it works more often than not. Travellers frequently make bad impressions upon foreigners, particularly if they believe themselves inherently superior, as they usually do. But they spread information about themselves and bring back new ideas. If they are sufficiently numerous, they tend to break down economic and intellectual barriers between nations. When personal aircraft allow Americans for instance to spend short holidays in Mexico, they may be able to get along with the Mexicans as well as they do with the French Canadians to-day. And as for Europe, that little peninsula will have to work very hard to keep its nationalistic hatreds up to fighting pitch.

ELECTRICAL COMMUNICATION

I am not going to go very deeply into the "gadgetology" of the telegraph and the telephone, whether

wired or wireless. With the single exception of wireless broadcasting—not exactly a telephone—these devices have been familiar in fundamental principle for a long time and have already had their chief effect upon our lives. The electric telegraph and the submarine cable worked a profound revolution, of course, modifying the methods of government and business alike. But that was long ago. The telephone is a little more recent. It enabled individuals to communicate easily over moderate distances, encouraging economic and social co-operation. Over long distances it has had less effect. The old-fashioned telegraph was almost as good. The transoceanic telephone has had almost no effect at all, chiefly because few people want to talk across the Atlantic or the Pacific except for novelty's sake. The rates are far too high.

All these means of communication have improved technically within the last few years, but they have not become appreciably more useful than they were ten years ago. The automatic telephone exchange is a marvel of mechanics, but it has not made telephoning notably quicker or cheaper. The teletypewriter, which allows any unskilled person to send telegraph messages, has not affected the cost or the speed of a telegram. Intercontinental wireless is no faster than the old-fashioned cable. The apparatus is certainly cheaper to operate, but the rates between countries have not been reduced in consequence.

There is only one important development on the horizon in this field, the utilization of ultra-short wireless waves in the neighbourhood of ten metres (30,000 kilocycles). These behave rather like ordinary light. They travel in straight lines and are absorbed or reflected by obstacles. They have two advantages. First, the "ether" is not crowded in this part of the spectrum. And second, the ultra-short waves can be concentrated into beams like those of a searchlight, reducing interference and giving

a measure of privacy. The chief disadvantage is that these waves do not follow the curvature of the earth, but fly off into space at the optical horizon.

Much feverish work is being done in this field at present. It is thought that relays of ultra-short wave transmitters may replace long-distance telegraph and telephone lines. They are less costly and easier to keep in repair. A great many messages may be sent over one channel, and there will be very little trouble with interference, fading, or static.

But if telegraph and telephone history repeats itself, the general public will not receive much benefit from this or any similar development. The policy of the communication companies has never been to pass operating economies on to the customer in the form of reduced rates, as public utilities are supposed to do. There is considerable mystery about how they manage it—financial magic of the highest type.

It is chiefly the old story of "protecting the investment" in obsolete equipment. The simplest example is the continued existence of submarine cables. It requires thousands of miles of extremely expensive cable to cross an ocean. Large ships must be kept in readiness to repair the lines, which are often damaged by anchors, sea animals, and earthquakes. They are by no means free from disturbances akin to static, and their capacity is comparatively small.

Transoceanic wireless requires only two stations, which are vastly cheaper to build and operate than the cables. The use of different wave-lengths at different times has removed the last vestiges of undependability. But nevertheless the wireless charges the same rates as the cable. This is because the cable companies, by means of alliances with the land-wire networks, have prevented wireless from under-cutting their monopoly. If it should try, it would have no effective means of delivering or collecting messages.

The situation on land is much more complicated. I shall not attempt to penetrate it here. But it is certain that the telephone and telegraph companies have not passed on the benefit of their technical improvements to the public in the form of lower rates, although a considerable reservoir of them has accumulated in the course of the last ten years. Probably by the time this book is published a Congressional investigation will have started the task of breaking the jam. Let us wish it all kinds of luck. Communication engineers have accomplished wonders in economy and efficiency, but in recent years their work has done society hardly any good. Operating economies which get lost in the meshes of finance are worthless, for they do not encourage wider use of the equipment. They may build up a number of well-camouflaged fortunes, but they do not lower communication rates for the public.

Another method of communication which has become entangled in commercial flypaper is wireless broadcasting. This was almost inevitable from the beginning. As soon as broadcasting became popular, it presented several wholly unprecedented problems. Who was to pay for the programmes? Who was to control them? Who was to "own" the ether?

In Europe the answer to all these questions was, "the government". Europeans generally pay a small tax for each receiving set, and the government undertakes to provide entertainment, news, etc. The trouble with this system is that almost all the governments have turned the wireless to political uses, often of the most objectionable sort. The "air" over Europe is now a wild confusion of propaganda and counter-propaganda. Moscow attacks Hitler nightly. Hitler spreads his odd ideas in several languages. France, Italy, and many of the lesser countries join in the chorus to the best of their ability. An honourable exception is England, which has in general refrained from using

wireless to annoy her neighbours or mislead her people.

In the United States the time-honoured "American way" was chosen. The ether was parcelled out—a common national resource if there ever was one—to the first to ask for it and applicants were told to go ahead and make money if they could. The extremely valuable "channels" became a kind of private property. As soon as the habitual listeners grew numerous, the economic problem was solved for the owners of the air. Advertisers found what they'd been seeking ever since their art was born: a medium which was almost unavoidable and which reached the mind of the victim when it was least prepared to resist.

So broadcasting in the United States, although it does not devote itself to any important extent to political propaganda, has become a sort of million-tongued huckster, forcing upon the public goods which are chiefly notable for their high percentage of selling cost and for their appeal to the weakest of minds. Since near-illiterates are the best market for this class of merchandise, the programmes are kept on a low intellectual level. There is comparatively little attempt to interest the upper third of the population, for this class cannot be persuaded to buy fantastic patent medicines to cure imaginary ills.

It is hard to say which method is the worse, the European or the American. But at least in the United States there is a better chance to benefit from a technical improvement which has been developing rapidly in the last few years. In the "broadcasting band" from 200 to 500 metres the air is crowded and channels are few. They are all considered valuable property and are held tightly by the early birds who were on hand when they were being passed out.

But in the short-wave bands there are plenty of channels. Most of them have been assigned in various

ways, but they are so numerous that unless the government decrees it, they cannot be monopolized by a few large advertising interests. Television is planning to take the lion's share of them, but there will probably be a few left over for entertainment not designed for thirteen-year-old minds.

At present the wireless manufacturing industry is enjoying something very like a boom. Part of the public has surprised the broadcasting companies by becoming sufficiently bored with their programmes to search for better things: police calls, faint European stations, aeroplanes in the fog—anything but crooners and advertising. The manufacturers have met this want by providing "all-wave" sets which are selling like hot-cakes.

When these sets become numerous, we may at least hope for two results. In the intervals between their propaganda many foreign stations provide very intelligent entertainment, some of which can be heard on short-waves. American stations, for fear of losing a part of their public to Paris or London, may devote more attention to adult, non-prostrate minds. It will not cost them much, for short-wave transmitters are comparatively inexpensive, and they can get channels for the asking. If the broadcasters do not choose to make this concession, there is a chance that competition may develop. It is a rather slim chance, for the owners of the present "broadcast band" may be able to capture all the short waves as well. But if the short waves do not get tied up, it may be possible for any man with a few thousand dollars to bid for public attention in the manner of a publisher or a theatre manager.

This, I think, is the brightest spot on the horizon in the broadcasting field. Wireless sets, both transmitters and receivers, are sure to improve in the future, but they do not need to improve very much. They already perform their technical duties with near-perfection. What

they need in order to serve society to the fullest is a little more freedom from commercialism. The short waves may force it upon them.

TELEVISION

In discussing this promising but unborn child of wireless broadcasting, I am going to describe its state of development at the present time. Then I shall list the very serious obstacles which are keeping it from extensive practical use.

Television is *almost* perfected. That is, we have means of sending a moving image of good quality through the " air ". The pictures are still small, but they are clear. The apparatus is not prohibitively expensive or complicated. It need have no moving parts. It can " see " a football game or the face of an entertainer or public man. Anybody can work the receiver.

The fundamental principle of television is extremely simple. It is best explained through the " facsimile transmission " of photographs, which is related to it rather as the lower animals are related to man. In one form of this apparatus the picture or diagram to be sent is wrapped around a revolving cylinder. A small spot of light shines upon it as it revolves. When the spot is on a dark portion of the picture, little is reflected. When it touches a white portion, it gets brighter. A photo-electric cell watches the spot and turns its changes of brightness into fluctuations in an electric current. Each turn of the cylinder " scans " a thin line across the picture, the spot moving sideways slightly at intervals so that it covers new ground for each revolution. Finally the whole picture is covered.

The fluctuating current from the photo-electric cell flows along a wire or is impressed upon a wireless " carrier wave ". It does not matter which. At the

other end is some device which gives off light in proportion to the intensity of the current from the cell. Obviously it will give off more light when the original scanning spot is on a white part of the picture and less light when it is on a dark part.

This fluctuating source of light is made to play on a photographic film mounted on a cylinder exactly as large and revolving at the same speed as that the original picture is mounted upon. Then as the second cylinder revolves, the light will impress upon it in negative, line by line, an image like the picture. The two spots of light will always be of corresponding brightness and they will cover their cylinder in unison. If the apparatus is sufficiently good, the duplication will be practically perfect.

Various forms of this device are in use. They can send not only photographs, but diagrams, handwritten manuscript, copies of legal documents, fashion drawings, etc. They have no great utility at present. So few of the machines are available that in most cases it is faster to send the material by air mail.

There are two chances that facsimile transmission may become important. The mechanism may be improved to such an extent that it will become the cheapest method of sending certain types of telegram—syndicated newspaper articles for instance. These are more numerous and have to be more timely than most news photographs.

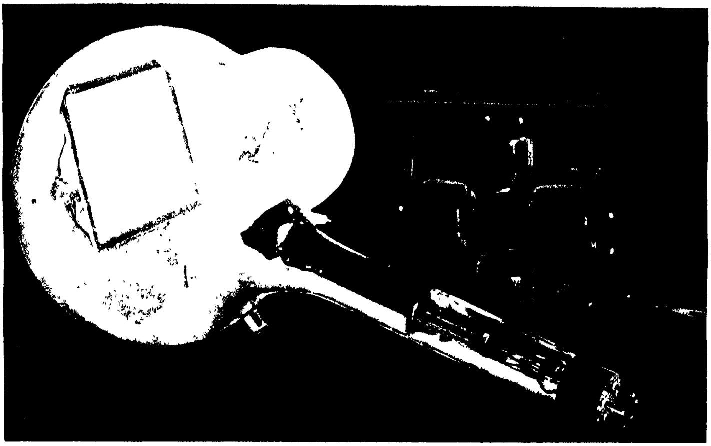
The wireless manufacturers have a bold scheme of including a simple facsimile receiver in their sets. The newspapers have bullied most of the broadcasting stations into abandoning one of their most valuable functions, the instantaneous distribution of "hot" news. They accomplished this feat by threatening not to print the programmes. If facsimile transmission could perform this duty, the broadcasting stations could defy the newspapers and send out fresh news flashes instead of stale ones.

But facsimile transmission is chiefly interesting as a crude ancestor of television. At present it is very slow, taking several minutes to send a fair-sized photograph. But if the images could follow one another as fast as those on a movie screen, 24 per second, they would give the illusion of continuous motion. The immensely greater speed required is the only essential difference between facsimile transmission and television. The face of an entertainer cannot be wrapped around a revolving cylinder, of course. The two spots of light must do the moving themselves. But the fundamental principle is the same.

There are many claimants for the honour of inventing the first successful television apparatus. J. L. Baird of England seems to have the best claim. His mechanical system, first exhibited in 1926, is considered wholly obsolete, but it is worth describing as an approach to the methods used at present.

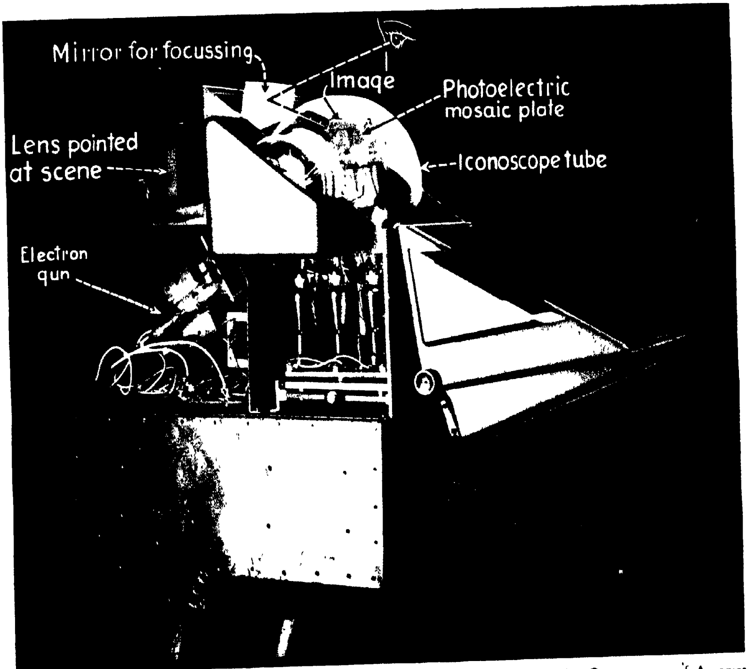
Baird "scanned" his subject with moving spots of light which passed through holes near the edge of a rapidly revolving disk. The holes were so arranged that every part of the subject was touched by one of the spots during each revolution of the disk. A photo-electric cell "watched" the passage of the light spots. When a spot was moving over a bright part of the subject, such as a man's forehead, the cell gave off a comparatively large current. For dark portions, like the hair, the current was smaller.

At the receiving end of the apparatus, the process was reversed. The fluctuating current from the cell, much amplified, caused a large neon lamp to flicker. Between the lamp and the eye of the observer was another perforated disk exactly like the first and moving at exactly the same speed. The observer could see through the holes only the portion of the lamp which corresponded to the part of the subject over which the spot of light was passing at that instant. When the



By courtesy of the Radio Corporation of America

ICONOSCOPE TUBE WITH MAGNETIC COILS FOR DEFLECTING THE CATHODE RAY IN PRACTICE THESE COILS ARE FITTED AROUND THE NECK OF THE TUBE



By courtesy of the Radio Corporation of America

TELEVISION CAMERA

lamp glowed brightly, it meant that the spot was touching a bright portion of the subject. The moving disk allowed this flash of brightness to be seen by the observer only when the proper hole was in the proper position. He saw brightness only where brightness ought to be.

These flashes followed one another with great speed, so fast that they seemed to be continuous. What the observer thought he saw was a large number of them arranged closely over a small area on the surface of the lamp. Each spot was glowing with a brightness corresponding to the brightness of the similarly placed spot on the subject at the other end of the line. Since the disks revolved about twelve times per second, the slowness of the eye merged the successive images into a picture giving the illusion of motion. If the subject smiled, the image smiled, though very vaguely.

There have been hundreds of variations on this mechanical system. They all have the same fatal defect. They are not fast enough. The quality of a picture, whether moving or not, depends essentially upon the amount of detail which it contains. The function of the scanning disk is to divide the face of the subject into a large number of parallel " lines " which have different brightnesses along their length. The more of these lines and the faster their brightness fluctuates, the more detail there is in the picture.

Here is where the mechanical systems fall down on the job. To obtain a good picture of decent size, their disks or corresponding parts would have to move at vastly greater speed. This they have never accomplished. The best of the modern mechanical systems give rather vague images with only about 60 lines of detail in the picture. The minimum for good entertainment value is at least 300. It is possible that this number might be reached by mechanical means, but the difficulties would be tremendous. The machines would have to contain parts moving so rapidly that they would be not only

very expensive and difficult to control but actually dangerous.

It is not necessary to go to such lengths. The modern systems using cathode rays have no mechanical moving parts at all. They cut out all spinning disks, lenses, and mirrors. They can " break up " a subject into as many as 360 lines—about the detail of a good home movie on 16-millimetre film. It is pretty generally agreed that the future of television belongs to the cathode ray.

Cathode rays are streams of rapidly moving electrons. The property which makes them valuable for television is the fact that they can be deflected by magnetism, like a spray of water droplets blown in the wind. Since electrons have no weight in the ordinary sense, they respond instantly to changes in the strength of the magnetic coils controlling their direction of motion.

If a cathode ray, instead of a beam of light, is used to " scan " a subject, there is no practical limit to the speed with which it can do so. It can divide the subject into a very large number of " lines of detail ". Its scanning motion is caused by variations in the strength of electromagnets, and these can change their power much more rapidly than necessary for this purpose.

Streams of electrons, of course, cannot be played directly upon the face of a subject. They cannot travel very far except in a vacuum, and even if they could, the subject, if animate, would cease at once to co-operate. Cathode rays are dangerous things. So a more indirect method has to be used. I am going to describe only one of the several systems, the so-called " iconoscope ".

The heart of this device is a " mosaic plate ", consisting of a sheet of thin mica which carries upon one surface millions of minute globules of silver coated with cæsium oxide. They do not touch one another, and are insulated electrically. On the other side of the mica is a sheet of metal called the " signal plate ". This combination is mounted inside a large vacuum tube

in such a way that the image of the subject to be "televised" can be focused upon it by means of an ordinary lens.

Cæsium oxide has a curious property. When light strikes it, electrons fly off. The more light, the more electrons. So when the image is formed on the plate, each globule begins giving off electrons in proportion to the intensity of the light reaching it. These are attracted away out of trouble by a positively charged metal coating on the side of the vacuum tube.

But electrons are negative electricity. When they move away from an insulated object like one of the globules, they leave a corresponding excess of positive electricity behind. Thus each globule becomes charged with positive electricity whose amount is greatest where the light is strongest. This charge affects the electrical condition of the signal plate directly behind each globule. If the charge on a globule could be neutralized in some way, a small current of electricity would flow out of the signal plate, and its strength would be proportional to the charge on the globule neutralized and therefore proportional to the strength of the light falling upon it.

This is exactly the specialty of the cathode ray. Its electrons neutralize the positive charges on the globules and cause a corresponding amount of current to flow from the signal plate. In the iconoscope the cathode ray comes from an "electron gun" at the other end of the tube. Its stream of electrons is whipped rapidly from side to side by changes in the magnetic strength of coils outside the tube. Thus it scans the light-image with tremendous rapidity. As it hits each globule, the current given off by the signal plate at that instant is proportional to the strength of the light which had been falling upon the globule. Thus the picture is transformed into fluctuations in a current—exactly what Baird's transmitter did, but with no moving parts at all and much faster.

Cathode rays have another peculiar property which enables them to be used in television receivers as well as in transmitters. When they fall upon certain chemical substances, they cause them to " fluoresce " or glow with coloured light, usually greenish. The brightness of this light is proportional to the strength of the ray.

Television receivers are so made that the fluctuations of the current from the signal plate in the transmitter will control the strength of a cathode ray playing from one end of a large vacuum tube. A little farther on this modulated ray comes under the influence of magnetic coils outside the tube which cause it to whip back and forth or " scan ", keeping exact time with the ray in the transmitter. The far end of the tube is flattened and coated with a fluorescent chemical (willemite, a form of zinc sulphide). This glows when the ray hits it and forms the image.

At the exact instant when the first cathode ray is releasing the charge from a certain part of the illuminated mosaic, the second ray is causing the corresponding part of the fluorescent screen to glow. If the light on that part of the mosaic is strong, the fluorescence of the screen is bright. If the globules of silver and cæsium are getting only the faint light reflected from dark clothing or hair, the corresponding part of the screen shows the relative darkness faithfully. The cathode ray moves so fast that it " paints " twenty-four complete pictures a second.

There are other cathode-ray systems besides that described above, but they all take advantage of the weightless responsiveness of a stream of electrons under the influence of shifting magnetic forces.

So much for the mechanism. The important question is what it will do. Television as a stunt or " marvel of science " is one thing. Television as a useful entertainment or communication device is quite another. The pictures must be clear and detailed. They must be

bright enough so that they do not have to be viewed in a totally dark room. They must be large enough so that several people can watch them simultaneously.

Television now has about the clearness and detail of a 16 mm. movie. This means between 300 and 400 horizontal scanning lines with similar detail in the other direction. The images on the end of the tube are 5 inches high by 7 inches wide, about the size of a small school-book. They are bright enough to watch in daylight, and the experimenters are confident that they will become somewhat brighter soon, so that they can be enlarged optically to 10 inches by 14. They do not flicker like the early movies. They will show " close ups ", scenes including several full-length figures, and outdoor events such as football games and public ceremonies.

In general, they should be compared to a well-made amateur movie on a small screen. They cannot be used in a theatre because the images are not bright enough to be enlarged to such size. In colour they are a rather unpleasant green, but this is not regarded as a serious defect. The eye ignores colour after a very short time.

Whether the above qualities endow television with " entertainment value " is open to debate. Few home movies are entertaining in any degree except to their makers, but this is not the fault of the camera or the projector. It is probably the same with television. If the programmes were good enough, the present apparatus would reproduce them with sufficient faithfulness to interest the audiences.

Such being the case, we come to the question, " Why isn't television functioning to-day ? " There are many reasons. In the first place, there are two schools of thought among television engineers and promoters. One believes that the time is already ripe for a gradual, experimental attempt. This was done with wireless. At first the apparatus was poor and the programmes were

wretched, but the public became increasingly enthusiastic nevertheless.

This opinion seems to prevail in England, where the British Broadcasting Company is planning to put television programmes of some sort on the air. Conditions are more favourable in England. Four or five stations will reach most of the population, and the short distances between them can be bridged with comparatively small expense. Also the government broadcasting system does not have to depend upon advertising revenues for support.

The other school of thought believes that such a premature attempt would be fatal, in the United States at least. It is convinced that nothing should be done until it is technically, economically, and artistically possible to provide a considerable fraction of the population with programmes which will arouse real enthusiasm. This is not the situation at present. I shall take up the chief technical obstacle first and leave the much more serious economic barriers until later.

The trouble at present is not so much in the " camera " or the receiver, but in the transmission of the pictures over long distances between them. It can be done and has been done, but the difficulties are serious. This is chiefly because television " signals " fluctuate much faster than sound wireless signals and so require a much wider band of ether waves to carry them. An ordinary broadcasting station is usually assigned a " band " ten kilocycles wide. It could get along with less. But a television station would need a band at least 2,000 kilocycles wide, about as much as all the broadcasting stations put together.

No free band of such width exists except in the ultra-short end of the spectrum, between 1 and 10 metres. The most promising region is from 3 to 8, where there is room for about ten television transmitters. But waves of this length, although free from static and fading, have

one very serious defect. They do not travel more than a small distance beyond the optical horizon. This means in practice that even if the transmitter were located on the top of a New York skyscraper, it would reach a circular area only about 20 miles in radius. So if television were to be available to even one-quarter of the population of the United States there would have to be at least one transmitter in each of the thirty-odd cities of more than 250,000 people. And each city would "see" only one station.

This is bad enough, for in the U.S.A. wireless finds a large proportion of its listeners among isolated farmers and the bored inhabitants of small towns. But broadcasting in America is confronted by another problem still more serious. The most attractive programmes of present-day broadcasting stations do not as a general rule originate in the studios of the local stations, but are sent by land wires from a central point, usually New York. This is not as easily done with television. The signals will not travel over ordinary wires. They require a conductor which consists of a copper pipe with a wire strung through its centre on insulating disks. This is too expensive for practical use over long distances at present. The signals might be sent by short-wave wireless delays, but this would mean stations every 30 miles—perhaps less expensive than copper-pipe conductors, but still extremely expensive.

So for many years at least, each city would "see" only the local talent at the disposal of a single station. There would be no ranging around the world for programmes. The audiences of Denver would have to watch Denver comedians. Only on very rare occasions would they see Rudy Vallée or Eddie Cantor. This would certainly limit the entertainment value no matter how good the apparatus might be.

But the most serious obstacles of all are economic. The cost of television stations to cover even a quarter

of the national population would be immense. It would require thirty or more transmitters, which are much more expensive than sound stations. Each would have to have an elaborate studio with lights, scene shifters, and all the equipment and staff of a theatrical stock company. If the stations were connected with one another, which would be necessary to hold the interest of the audiences, the total cost would rise well into nine figures. It is variously estimated at between £40,000,000 and £120,000,000.

This does not include the cost of the receiving sets, which would cost at least £40 each and would involve enormous expenditure on the part of the public. At present no one thinks that the public has the loose cash to invest in very dubious entertainment.

Still, the miracle may happen. Television has an extremely bad reputation among investors at present because of certain things which happened during the late boom, when it was promoted as the "next great industry". But several of the largest wireless companies have faith in it and are spending a great deal of money on research. They remember that not long ago wireless itself did not look like a money-maker. When technical problems are solved, the economic problems have a way of solving themselves.

There is a good chance that another great boom may set television upon its feet. What it needs is an investing public willing to take a long chance and a buying public with plenty of money to spent on £40 sets. When these two essentials are on hand, the other economic difficulties may disappear. Sponsors will come forward, eager to show to the public the actual patent-medicine bottles themselves. The movie producers may co-operate and allow brief tantalizing glimpses of their stars, for the same reasons that they print their pictures in the papers. Florida and California realtors will bring their palm trees and sunshine to cold Northern homes. Propa-

gandists of all sorts will pay high prices for the chance of reaching people who not only do not read, but cannot even understand clearly the meaning of a spoken sentence.

It is not altogether a pleasing prospect. Television broadcasting will be much more expensive than sound broadcasting. Therefore we must make up our minds to comparatively inferior programmes with a larger content of advertising. The opportunities for political propaganda will be enormous. Popular leaders will be able to affect the minds of their supporters by eye as well as by ear. The Nazis, as a matter of fact, have recognized this possibility already and are making strenuous efforts to establish television in their country so that all Germans may look daily upon the faces of Hitler, Goering and Goebbels.

Nevertheless, in spite of the misuse which will be made of it, television is a technical achievement which *should* favour the progress of civilization. If controlled by rational, well-meaning governments, it would allow neighbouring peoples to become really acquainted with one another. It would spread styles and preferences, allowing larger-volume production to fill our wants less expensively and so raise our standard of living. It would bring civilized sights to populations which are now able only to hear civilized sounds. It would speak a more universal language than the wireless, a crying need in a world of misunderstandings and unnecessary conflicts.

Every improvement in communication is ultimately beneficial to civilized life. For many years after its appearance television will be devoted, in U.S.A., largely to trade-marks and the faces of propagandists, commercial, political, even religious. Still, we should welcome it when it arrives. The world is large. If we ever manage to learn to work together and gather fully the fruits of our scientific discoveries, it will be with the aid of every means of communication at our disposal.

VIII

WHAT APPLIED SCIENCE OFFERS US

THE civilized world to-day may be compared to the kitchen of a high-class hotel, equipped with every conceivable cooking device, the pantries stocked with every kind of food. The human race is not numerous enough to tax the capacities of this kitchen, so let us imagine ourselves a small party of hungry people entering the dining-room for a meal. On such an occasion one question always arises. "What shall we order?" And another question sometimes follows. "What will it cost?"

In the bulk of this book I have tried to show that our kitchen, the civilized world, contains everything it needs in great abundance. It has plenty of power—the driving force of modern life. It has metals, of which we build our power-driven mechanical slaves. We shall never exhaust the reserves of any major metal, and the exhaustion of a minor one will not cause much inconvenience. Furthermore, we are learning to combine these metals into alloys with vastly superior properties.

We know how to construct the mechanical slaves themselves. In fact, we know how to make many more types than we are able to find work for at present. The slaves are becoming more willing and efficient daily. They will produce for us almost any material thing we ask for. They are hampered somewhat by the physical difficulty of delivering their gifts and obtaining the raw materials of which to make them, but transportation is improving rapidly. They cannot work efficiently on small lots. They are creatures of fixed habits. But

communication, which enables large numbers of us to agree to ask for the same gifts, is improving too.

In short, all the material conditions are favourable to a vast improvement of civilized life. No tangible thing is lacking, and we have more technical knowledge and skill than we have been able to use as yet. The human race is sitting at a banquet table, menu in hand, trying to make up its mind what to order, and worrying a little about the price.

Dropping the metaphor, let us see what technology can offer us to-day.

I have devoted most of this book to the essentials of civilized life—the materials, machines, and methods which we actually need in order to get more for our expenditure of effort. I have proved, I think, that nothing is lacking. We have the necessary equipment or know how to construct it. It remains to see what it will do for us. This depends upon what we want it to do, and whether we are willing to pay the price.

"Consumers' goods" are articles of direct utility to individuals, things which fill the wants of human beings. None of the subjects I have treated fall in this class, although some are border-line cases, such as private aeroplanes and television.

It is not possible to reason scientifically about the future of any type of consumers' goods, for this depends upon what people will want—an extremely uncertain matter. At various times the human race has attached great importance to strange things. Extracting a red dye from a rare shellfish was a major industry in the Roman Empire. Tremendous ingenuity and effort is still expended upon the collection of gold, much more than is justified by any property this metal possesses. Most nomadic peoples seem determined to own more horses than they can use. Many civilized women would like to have new clothing for every day in the year. The rulers of the Aztecs took great pains that the supply

of suitable victims for human sacrifice should not be exhausted. It is hard to predict what people will want.

Probably all sorts of bizarre wants will make themselves felt when and if our industrial machine gets running smoothly. Perhaps we shall ask for tropical flowers which last only one day, or penguin eggs from the Antarctic. Modern transportation can bring us these things if we demand them. Perhaps we shall want to see distant friends by television. This, too, is not wholly impossible. Perhaps we shall ask for elaborate equipment connected with some physical sport not yet invented. None of these wants is stranger than the present desire for pearls or summer furs or golf courses. You can judge an alloy by its chemical and physical properties. You can judge an engine or a production machine by what it will do. But the only test you can apply to consumers' goods is, " Do people want them ? " And human wants above the level of bare subsistence cannot be predicted by scientific reasoning.

But there are several important things which we do want and which machines are ready to give us with certain conditions attached. One of them is houses. At present most of us live in houses not much better than those of a hundred years ago and constructed by practically the same methods. We do not try to manufacture motor-cars or aeroplanes with the materials and equipment used by James Watt. We do not try to cross oceans in replicas of the Mayflower. But new houses to-day are hardly better than those our ancestors built with hand tools and local lumber. There have been a few improvements, mostly in the equipment, but the houses themselves are still manufactured on the spot by primitive, old-fashioned methods.

There are reasons, of course, for this curious technical lag. Houses are made at present out of materials—wood, stone, brick, and concrete—which do not lend themselves to machine-made methods. Their style is

governed by a tradition which forces them to have certain inconvenient conventional shapes, and at the same time decrees that they shall not resemble one another too closely. A man may strive to own a motor-car exactly like his neighbour's, but he wants to live in a house which is somehow distinctive, even though the differences are entirely unimportant. But the house must not be too different, or it will be considered " funny-looking ", like a rear-engine motor-car.

A curious thing about this preference is that people who move to city apartment houses do not object in the least to uniformity, novel materials, or unconventional outside appearance. But this broadmindedness does them no good, for large city buildings must be assembled on the spot, no matter what they are made of, or how. Too few of them are built and they are affected by too many local conditions.

None of these obstacles to the use of modern building methods are technical. They exist only in the public mind and are therefore subject to change without notice. If they could be reduced sufficiently to allow large-volume production, it is absolutely certain that modern factory methods would build us houses much better and much cheaper than any we can buy to-day. They would consist very largely of metal, steel for the interior structural parts and a corrosion-resisting alloy for the outside. They would be insulated against heat and cold with some material like mineral wool. In interior decoration they would not be very novel unless change were demanded.

Such houses would not have to be exactly alike by any means. The exterior finish could vary within wide limits. There could be many models built up of units of one or more rooms. Extra features to give distinction, such as sun-parlours and garages or aeroplane hangars, could be added at small cost. The mechanical equipment—the heating, cooking, and sanitary installations—might form the central starting-point. Around

it the house would be assembled, varying according to the size of the family or its special requirements. The American passion for gadgets could be amply satisfied. The house could be a maze of wires, pipes, lights, automatic doors and telephones.

The transportation difficulties are not very serious. Lumber, of which most small houses are built to-day, comes from much greater distances than steel, aluminium, or mineral wool. The houses would be shipped in knock-down form, and would be assembled on simple foundations by trained men. Several large trucks would be able to carry the average house, and their crews would do the setting up. Perhaps a few men would stay on the job after the trucks had departed to see that all the details were in working order.

Of course we shall not get such houses until it appears that enough of us will buy them. One hundred thousand a year is probably the minimum to keep one factory going. When the volume increases further, the price will fall, as it did with motor-cars

It is difficult to guess when we shall ask for factory-made houses in sufficient numbers to make their production possible. The best that can be done is to list the factors opposing and favouring this development.

In the first place there will be strenuous resistance from building-trades unions and real-estate interests. The carpenters, masons, etc., are the last old-fashioned hand workers to survive in any considerable numbers. They are anachronisms in a modern, industrial country, but they are tightly organized and very powerful politically. Their able leaders will do everything in their power to keep house-construction a hand trade. They will get valuable aid from the owners of real estate. This class is always on guard against any improvement which might impair investments. Tremendous capital will be required to start the industry, and it is probable under present conditions that the real-estate interests

through their influence on the banks could prevent its collection.

If these financial and social obstacles are cleared away, it is not likely that the public's architectural preferences will put up much resistance. People like to think that they have a " distinctive " house, but most of them are not distinctive at all except in minor details. Factory-made houses would be sufficiently flexible in size and design to allow for all functional preferences, and they could be made very variable in superficial appearance.

When motor-cars were novelties made in comparatively small quantities, a part of the public demanded custom-built bodies, merely so that their cars would not look too much like their neighbours'. The " special jobs " were never as good as the standard products of the factory and they were much more expensive. Now this business is almost extinct. At present even the richest buyers do not object to owning a car exactly like 10,000 others. True, they still like to choose the colours and extra equipment, but the buyers of factory-made houses would be able to make many more individual decisions than these without causing too much trouble for the plant.

Now for the favourable factors. Aluminium and other corrosion-resisting alloys are improving rapidly. They are almost sure to fall in cost. The motor-car industry has recently made great strides in shaping large sheets of thin metal. These methods will be available for house manufacture. People are becoming accustomed to more elaborate mechanical equipment in their houses. This is the item on which factory building will save the largest proportion of cost. All kinds of transportation are improving rapidly, which will make it less advantageous to use crude local material.

But probably the most important favourable factor is the approaching decentralization of population. Most people would prefer to live in thinly settled districts

if they did not have to spend too much time getting to work and reaching centres of amusement. This obstacle is being removed rapidly. All the impending improvements in transportation—better highways, motor-cars, suburban trains, personal aircraft—favour dispersion.

Factory-made houses are of little use in congested residential districts. They will never be made in many-family sizes with five or six stories, and they cannot conform to the layout of city streets, lots, etc. Their place is in suburbs, small towns, and country districts. When more people live in such localities, there will be more potential markets for individual houses of low cost.

Improved transportation will have another favourable effect. In the future, if our industrial machine runs properly, the average man of small means is likely to have a good deal more leisure. This will allow him to take his family to summer or winter resorts. He will want some sort of camp, or cabin, or seaside cottage for his stay, and the factory-made house will fill his needs exactly. " Distinctiveness " will not count for much. Holiday cabins to-day are apt to be much alike. Cheapness and quick erection are more important, and in these two qualities the factory-made house will excel.

If we ever do get factory-made houses we shall probably get air-conditioning thrown in. It is possible even to-day to create any desired " climate " within a dwelling-house under any outside conditions, but the cost is prohibitive. There are two reasons for this. All cooling devices consume a large amount of power, usually in the form of electricity, and the equipment including the necessary ducts, fans, etc., is extremely expensive to buy and to install.

If houses were made in factories, it would be very simple to build them with proper insulation. This would reduce the amount of power consumed by the air-cooling machine. The ducts could be included in the construction at small cost, and the rooms could be so arranged

that the cool air would circulate effectively, which is not the case in houses designed without this feature in mind.

The cooling machines themselves would be much cheaper if manufactured in large quantities and linked up with the other mechanical equipment in the house. Heating and cooling are related operations. It is not improbable that a heater may be developed which will act as an efficient cooling unit in summer. Many inventors are at work on this idea at present.

If it does become possible to cool buildings cheaply in hot weather, it will have a profound effect upon many phases of human life. At present no one works or thinks or plays very effectively when the temperature is above ninety and the humidity is high, which is often the conditions during the summer months. Cool houses, offices, and factories would add perhaps ten or more per cent to the year-round productiveness of the average community.

The effect in the tropics might be even greater. Life moves slowly in tropical countries, economic and intellectual life at least. There seem to be certain temperature and humidity limits beyond which human beings are not very vigorous. But unfortunately it is precisely the hot, damp jungle areas which are most productive agriculturally. Plants grow all the year round and give bigger crops for the labour expended.

The Amazon valley, for instance, could produce more than enough food for the whole world, but none of the races which can live in its climate without deterioration have proved sufficiently active to clear the jungle away and plant useful crops. White men who go there from the North or South do not remain healthy and vigorous for long. The same is true of the low, well-watered portions of Central Africa. This is why most of the world's crops are now raised in temperate regions where an acre will produce much less per year.

The world does not need more food at present. It cannot consume what it has. But if we ever do need more, air-conditioned houses may solve the problem of tropical agriculture by invigorating the native population or allowing imported white men to retain their health. Even if we don't need more crops, there may be a shift of agricultural effort towards the tropics.

There are many other things we want which machines will give us if we ask for them in sufficient numbers. It would be safe to say that at least half of the dull, monotonous labour in the United States is performed by women doing housework. Some of this—washing babies, for example—is beyond the capabilities of any machine, but much of it is wholly unnecessary. Women struggle with coal fires or breathe paraffin fumes not because they like to but because electric ranges are too expensive to buy and operate. There is no technical reason why practically all cooking should not be done by electricity. There is an excellent non-technical reason, however.

The domestic electricity rates are now so high that the average householder cannot afford to run an electric range. Therefore the ranges themselves are also expensive because comparatively few are manufactured. If current should fall in price, the cost of the ranges would fall too. The same reasoning applies to many other types of electrical house equipment—water-heaters, refrigerators, and air-conditioning machines. All of these things are on the market, but they are unduly expensive because the cost of the current keeps them from being bought in large quantities.

If current should fall throughout the country to its "natural" price—not much over a halfpenny a kilowatt-hour—many more electrical servants would appear as if by magic to lighten the work of the housewife. It is easy to think of innumerable things which electricity could do in the home if its cost were not so high.

But I am not going to spend more space on consumers'

goods. There are too many ifs. Modern applied science will provide us with all sorts of things very cheaply *if* we demand them in sufficient numbers, *if* we learn how to deal with the various non-technical forces which are interfering with the work of our mechanical slaves.

So I am going to end this book with a list of the most important obstacles which stand between us and the fruits of our technical discoveries.

IX

THE PRICE OF THE FUTURE

It is usually rather difficult to get technical men to talk about politics, theoretical economics, or sociology. Unless they are the presidents of universities or identify their fortunes with those of a large and opinionated corporation, their minds are likely to be almost blank as far as these subjects are concerned. But if you manage to get to the bottom of their feelings, you will usually find a sort of righteous indignation, sometimes mild, sometimes violent, but almost always present in some degree.

"What's the matter with the rest of the outfit?" they ask disgustedly. "We tell them how to raise all kinds of food, and a lot of people start eating garbage. We design a long-range plane for an air line, and they start wondering if they can drop bombs on Tokyo. We figure out a cheap and easy way to make something, and they all jump on us for causing unemployment. Wasn't that what they wanted us to do—save labour?"

In short, the technicians are perplexed as well as disgusted. The world, they say, asked them to do certain things, develop intricate and complex methods by means of which human beings could get what they want without so much effort. They believe they have done the job well. They know it, in fact. But they find themselves hampered at many points by forces beyond their understanding or control. And, furthermore, they find that they are being blamed for many of the troubles of society. With the exception of a few military developments, they cannot see that any of their discoveries

should do society any harm. But they are forced to admit that in practice many of them have proved disastrous. This, they protest, is not their fault.

They are right, of course. Technical men are specialists. When one of them designs an automatic machine to produce electric-light bulbs, he is thinking of the job itself, not of the effect his success is apt to have upon the glass-blowers. Glass-blowing is not pleasant or healthy work. A machine which can do it as fast as 500 men ought to be a good thing. That's as far as he thinks his reasoning need go. The rest is up to the non-technical leaders of society. If 10,000 glass-blowers nearly starve to death, it means that somebody else has fallen down on *his* job.

Sociologists have coined a fearsome phrase for this problem, " technological unemployment ". They talk about it as if it were the evil genius of the modern world, the cause of all suffering, the snake in Eden. But as a matter of fact it is merely a proof that the technicians have done well the job which society asked them to do. They were told to reduce the amount of human effort required to produce a given amount of desirable goods. They have done so. The result should be that human beings need work less for what they get.

Sometimes this happens, but not always. Often it turns out that some men work just as hard as before for only slightly greater rewards, while others don't work at all and either go hungry or become guilty-minded burdens upon society. The leisure won by applied science is not always distributed properly.

The technical men regret this when they see it happening, but they do not admit that it *has* to happen. They offer no remedies. That is not their job. They accept no excuses. To men who spend their lives with the definite realities of applied science, such things as credit inflation, buying power, confidence, and the gold standard seem very unconvincing indeed. They are inclined to

blame politicians, financiers and industrialists who think of their own selfish interests instead of the welfare of society. These should provide leadership, but they don't. It is their fault that leisure, hard-won from nature by science, should turn into unemployment, the chief cause of human distress.

This is how engineers defend themselves when accused of causing " technological unemployment ". To them economists are unsuccessful soothsayers. Sociologists are impotent sob-sisters. Politicians are either incompetents or crooks. " We've done our jobs," they declare. " Now you go and do yours. You've made a terrible exhibition of yourselves so far."

So much for technological unemployment. It is vastly important, for it is intimately tied up with purchasing power, depressions, the maldistribution of wealth and other economic troubles. But it is too large a subject to discuss here. I merely wanted to give the engineers' view of it. They consider it wholly unnecessary and the fault of incompetence and selfishness not their own. But they all agree that until we have learned how to deal with it in some way, we can never enjoy fully the fruits of applied science.

The next obstacle is more specific, although it also is caused by moral defects on the part of non-technicians. At present many of the most valuable industrial developments are being held up by selfish monopolies of various types. Aluminium and magnesium are simple cases. Both cost much more than they should, and their expensiveness hampers the engineers in many different fields. The light alloys of these metals would be used in innumerable ways if they were cheaper—particularly in transportation, but also in the building industry. Nickel is another " captive " metal, although much less important.

A more complicated monopoly is in control of electric current for domestic purposes and minor industries. It

is weakening fast, and when it falls, the resulting rate reduction will stimulate many developments, particularly in the field of consumers' goods.

Much less important in their direct effect upon industry are the communication monopolies—the telephone, telegraph, and commercial wireless. These masterpieces of financial intrigue do their greatest harm indirectly, by piling up money in the hands of men who do not put it back into circulation. The same is true, of course, of all extremely profitable businesses, but there is some excuse for large fortunes in industries where competition exists. In such cases financial success may be a sign of exceptional efficiency. But there is no excuse whatever for anyone to make great sums out of public-service monopolies. It does not show efficiency. It merely means that the public has been overcharged.

Then comes the extremely vexed question of international trade. At present the world is divided into a large number of nearly trade-proof compartments. I shall not attempt to list the reasons for this. They range from plain commercial highway robbery to that even more damaging thing, "sincere" muddle-headedness. But all tariffs, quotas, and embargoes have the same effect upon society. They protect inefficient industries from the penalties of their own failings and so keep their productiveness below what it would be if they were forced by competition to adopt the best methods.

This affects practically all industry to-day, agricultural as well as manufacturing. There is no excuse, for instance, for beet sugar. It takes only about one-fifth as much effort to grow cane sugar in the tropics. If it were not for trade barriers, not a single sugar-beet would be raised anywhere except as stock feed, and the world would get its sugar supply with much less effort.

But by far the worst effect of these trade barriers is upon the manufacture of complicated articles such as

motor-cars, electric motors and mechanical equipment in general. The advantages of large-scale production are so overwhelming in these lines, that there is no possible excuse for making similar units in more than one locality. If Detroit made all the motor-cars in the world, everyone would get them less expensively, especially the inhabitants of European countries which try to support pitifully feeble factories of minute output. America might join in the benefits by getting its Diesel engines from large-scale plants in Germany, its textile machinery from England, and its transformers and electric meters from Sweden.

If all tariffs were removed overnight, there would be a period of confusion, no doubt, but it could hardly be worse than what we have passed through in the last four years, and the technical benefits would be enormous. Each industry would pick the country where conditions are most favourable to efficiency. There would be no small, ineffective plants protected by artificial barriers. " Technological unemployment " would certainly increase, but no one should consider this an objection. It would merely prove that the manœuvre had been a success. When society is organized rationally, it will not be impossible to distribute agreeable leisure to the people who can use it.

Tariffs and their relatives are intimately connected with nationalism, that silliest and most damaging of all emotions. Nationalism leads ultimately to war, and in the meanwhile it makes us prepare for war at great cost in useless labour.

It would be interesting to estimate what part of all human effort is wasted in learning the art of large-scale murder and in manufacturing the proper instruments, but the figures are not available. They are certainly large, and everyman-hour spent on drilling, manœuvring, and making weapons is a clear loss to society. For all the good it does us we might as well pay twenty

million men for making gumdrops and dumping them into the sea.

This would be rather an improvement, in fact, on preparing for war, for the gumdrop makers would not be planning to murder one another and a large part of the rest of the human race as well. When the "next war" finally arrives, it will be far worse than any newspaper sensationalist has ever imagined. It will extend to every cranny of the world. An aeroplane is being manufactured in Maryland at this moment which will carry a thousand pounds of bombs 9,000 miles. Subtle poisons are available which laugh at gas masks. An excellent technique of plague-spreading has been worked out in detail. Famines will be fostered by propagating destructive insects and plant diseases in enemy areas. The new science of electronics will certainly enter the fray, perhaps with some wireless-active device or material which will destroy the fertility or sanity of all human beings it approaches.

The most alarming thing about the next war is that offensive weapons have far outdistanced defensive ones. No one who is not directly connected with the manufacture of anti-aircraft guns thinks that there is any way of protecting a city from air attack. Bombing planes will fly so high that they cannot be seen or heard even in daytime. They will be manufactured in large numbers by mass production, and they will be able to cause any desirable amount of death and destruction.

It is possible to say that war is an inevitable result of "human nature". Many men hold this opinion—especially those who hope to benefit by war. But so are all the other obstacles to the orderly growth of civilization. They all originate in certain human traits—shortsighted selfishness, blind devotion to tradition, the desire to dominate and destroy. We can't get rid of them until we change "human nature". Conservatives like to consider this impossible.

But we *can* change human nature. It has changed many times in the past and will certainly change in the future. All through history and prehistory we have been learning how to check those human traits which interfere with effective co-operation for common ends. We have gradually discovered that we can lead more satisfactory lives if we do not spend our energies upon useless conflict.

The first advance in this direction was perhaps when we learned how to combine against bullies who had exceptional physical strength. These rugged individualists are not apt to make good leaders. Their intelligence rarely measures up to their muscular development. It was once " human nature " to admire and submit to them, but this has changed. Heavyweight champions are admired by some Americans, but they do not become Presidents of the United States.

It was once " human nature " to steal cattle, pretty girls, and other desirable objects from the next village. This has been stopped by gradually extending the areas within which such enterprises are forbidden. Now only large nations go on raiding expeditions. Once it was considered " natural " for men to own other men body and soul. The Roman Empire was built on this practice and fell because of it. Now slavery has been recognized as dangerous to owners as well as to slaves. We don't allow human nature to express itself in this way.

So I think we can look forward to certain desirable human changes in the future. It is certainly " natural " for rich men to damage the interests of all their fellows by monopolizing a raw material or a service, but we can learn how to curb them as we curbed the muscular champions of prehistoric times. It is " natural " that those persons who find themselves in pleasant circumstances should attempt to hinder advances which threaten their position, thereby causing " technological unemployment ", depressions, etc. We will learn to deal with

million men for making gumdrops and dumping them into the sea.

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